



CPS 2019 Agricultural Water Treatment RFP FINAL PROJECT REPORT

Project Title

Agriculture water treatment – Southwest region

Project Period

November 1, 2019 – April 30, 2021 (extended to July 31, 2021)

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Objectives

1. *Determine reductions of pertinent foodborne bacterial pathogens (Shiga-toxigenic Escherichia coli), non-pathogenic indicators, E. coli and Total Coliform bacteria in surface water samples from four major growing regions in Arizona (2) and Texas (2), which will establish robust inactivation data for target treatments (calcium hypochlorite, peroxyacetic acid (PAA), and UV light). This will result in documented scientific-data, which growers can use as justification for validity of their antimicrobial treatment.*
2. *Conduct in-field evaluation of the most appropriate treatment dose per chemistry with grower collaborators. This will effectively allow the research team to study treatment systems when utilized for commercial scale production and document key criteria which must be monitored and documented when designing, implementing, and managing effective antimicrobial water treatment systems on-farm.*
3. *Concurrently with Objective 2, evaluate the accuracy of commercially available and emerging test strips/kits and on-farm cloud-based data monitoring systems for quantifying the effectiveness of antimicrobial water treatments as well as a range of physical and chemical parameters.*
4. *Evaluate the short- and medium-term impacts on soil/plant microbial communities in response to antimicrobial water treatment as well as define a metric of soil health.*

Funding for this project provided by the Center for Produce Safety through:
CPS Campaign for Research

FINAL REPORT

Abstract

Recent metrics changes to the Arizona and California Leafy Greens Marketing Agreement(s) (LGMA) now require growers utilizing surface water for overhead irrigation, to treat their water within 21 days of harvest. For many producers, this is the first time that water quality data may indicate the need for antimicrobial treatment of agricultural water as a corrective action before irrigation can be applied safely. Exacerbating these challenges, growers are faced with a myriad of options related to antimicrobial water treatment, with very little guidance on the most appropriate treatment option for their ranch, or the requirements needed for successful implementation. With limited guidance, water treatment decisions are likely to be unsuccessful and expend both excess time and money without the ultimate outcome of eliminating generic *E. coli* (non-detect per 100mL), and reducing total coliform bacteria (≤ 99 MPN/100mL). Unsuccessful treatments will likely lead to little or no reduction in potential pathogen loading in an agricultural water source and thus little to no reduction in microbiological risk. CPS-funded studies conducted by Dr. Rock characterizing the microbial quality of water used to irrigate fresh produce in the Southwest found that foodborne pathogens are present in surface waters (Rock and Gerba, 2014) and that treatment options can be highly variable (Rock, 2019). Grower guidance is needed on antimicrobial agricultural water treatment options available to industry and monitoring strategies to ensure successful treatment and ultimately the protection of public health. Over the course of one growing season, the research team evaluated the efficacy of three antimicrobial treatments (Peroxyacetic Acid - PAA, Calcium Hypochlorite, and Ultra Violet Light) across four produce growing regions of the Southwest: Yuma, AZ; Maricopa, AZ; Edinburg, TX; and Uvalde, TX. **The overall goal of this research was to develop scientific data that support produce growers to better manage their use of antimicrobial agriculture water treatments in the Southwest.**

Background

Recent outbreaks traced to fresh produce, coupled with heightened media coverage, have elevated produce safety to the forefront of public attention. More specifically, the 2018 outbreak, involving romaine lettuce grown in the Yuma region, was linked to *Escherichia coli* (*E. coli*) O157:H7, in which agricultural water was suspected as the source, yet the origin of the outbreak strain remains unknown. In response to the outbreak, the California and Arizona Leafy Greens Marketing Agreement(s) adopted revised metrics in an attempt to address the possible role of irrigation water in crop contamination. Revised metrics now require growers to treat their irrigation water when using surface water for overhead irrigation within 21 days of harvest, with a target goal of non-detect generic *E. coli* and 99 or less total coliform bacteria per 100mL of irrigation water post-treatment. Such rapid changes, in tandem with a reduced time frame for implementation, have left the fresh produce industry in need of guidance on antimicrobial treatments that are proven to be both viable for their operations and successful.

The need for water treatment guidance is also heightened by expected FDA regulations for the sampling of irrigation waters used for produce production for generic *E. coli* as an indicator of the potential presence of fecal contamination. While the agricultural water rule is still pending, in general it is designed to reduce the risk of produce contamination and to provide guidance on sampling frequency, location, and source of irrigation water. The rule also states that in the event that an irrigation source does not meet water quality requirements, that treatment options may be implemented as a corrective action to bring the water source back into use. When treating the water source, the Produce Safety Rule (PSR) requires that a grower must use an EPA-registered product and that the use of that product must follow label guidelines. **Table 1** provides an outline of the various water treatments available for agricultural water treatment based on their mode of action.

Table 1. Common Antimicrobial Agricultural Water Treatments

Water Treatment	
Chemical	<ul style="list-style-type: none"> • Peroxyacetic Acid (Activated Peroxygen, PAA) • Chlorine / Chlorine Dioxide • Sodium or Calcium Hypochlorite • Copper / Silver Ionization • Ozone • Bromine • Electrolyzed Water
Physical	<ul style="list-style-type: none"> • Heat Sterilization • Ultra Violet Light (UV) • Sand/Membrane Filtration
Biological	<ul style="list-style-type: none"> • Slow Sand Filtration • Wetlands

In light of the recent regulations, a number of resources have been developed to aid growers in decision making regarding irrigation water treatment, including a detailed spreadsheet constructed by the Produce Safety Alliance that provides an overview of sanitizers labeled for produce, the active ingredients, label information, the trade name, and additional product information (<https://producesafetyalliance.cornell.edu/resources>). While this tool is useful, knowledge gaps remain with respect to special considerations for water treatment selection as well as how a grower should validate and verify the effectiveness of treatment of their specific water source.

Ongoing research has demonstrated that numerous factors can influence irrigation water treatment effectiveness, with the most influential factor(s) being source water quality. Water quality factors, including biological loading, excessive organic matter, pH, and alkalinity, may all impact efficacy of water treatment. Additional aspects that should also be considered by growers when selecting a potential treatment method include: capital cost, operating/

maintenance cost (including energy requirements), treatment costs, efficacy of treatment (concentration and contact time), phytotoxicity potential, ease of use (the mobility/immobility of treatment equipment), amount of water to treat, documentation and data recording options, and worker safety.

In a recent study (2019 CPS Rapid Response – Yuma Valley) of irrigation systems and water sources, the Rock group evaluated the variability of two antimicrobial agricultural water treatment options available to industry. While both treatment methods were effective at reducing microbiological loading in the source water, closer investigation into sample collection strategies, residual disinfectant monitoring, and time for irrigation system stabilization highlighted the complexities in antimicrobial treatment validation and verification.

Agricultural microbiomes within phyllospheres (plant), rhizospheres (root zone), and soils are highly diverse, and are also vital to effective crop production around the world. However, these microbiomes are susceptible to diversity shifts in response to varying environmental factor. Variation in soil microbiome diversity in leafy green fields in Arizona and California were found to be due to a number of factors: soil chemical properties accounted for 12.5% of community diversity, while and soil physical properties accounted for 16.3% of variation (Ma et al., 2016). Studies have also shown soil salinity and pH alter bacterial communities by allowing salt tolerant or pH tolerant taxa to dominate (Rath et al., 2019). Several studies found that irrigation with treated wastewater impacted the overall soil and/or rhizosphere microbiomes in different crop production fields (Zolti et al., 2019). A single study examined the impact that chlorine dioxide disinfection of irrigation water had on the bacterial communities of the water, soil, and fresh produce (baby spinach). It was found that chlorine dioxide treatment did not significantly impact the diversity of the bacterial communities in the soil, water, or spinach, but there were significant changes in the relative abundance of certain bacterial genera in all three areas (Truchado et al., 2018). However, the study only examined one commodity (spinach) at a single timepoint (end of the season) under a single water treatment (chlorine dioxide) in a single location, so it is possible that results could vary in different locations under different treatments. Additionally, it is possible that irrigation-induced shifts observed during the growing season could resolve, with no impact to the crop, by the end of the season. Many questions remain about the impact on the soil, rhizosphere (root zone), and phyllosphere (plant) microbiomes after irrigation with water treated with different methods. This study observed these impacts and attempted to translate the results for the grower community that needs the information.

Research Methods and Results

Objective 1: Benchtop evaluation. Objective one focused on the evaluation of the antimicrobial treatments in controlling generic *E. coli*, total coliform bacteria and foodborne bacterial pathogen (Shiga-toxigenic *Escherichia coli*), all of which are microorganisms of interest

and concern to the produce industry. This evaluation allowed the research team to optimize treatment dose, record information on ease of use, treatment effectiveness, and pH adjustment requirements, among other variables. A total of 50L of irrigation water grab samples (two 25L sterile carboys) were aseptically collected from each of the four field locations using a standardized SOP provided by the University of Arizona. Water samples were overnight shipped on ice to the University of Arizona Maricopa Agricultural Center from Yuma, AZ, and Edinburg and Uvalde, TX, within 48 hours of collection. Water samples were collected on-site at the Maricopa Agricultural Center and transported on ice to the laboratory until use. Prior to use, water samples were evaluated for total coliform bacteria, generic *Escherichia coli*, and water quality parameters of pH, EC, and turbidity (**Table 2**).

Table 2. Water Quality Parameters of Agricultural Irrigation Source Waters of the Southwest

Water Source	pH	EC (uS/cm)	DO (mg/L)	Turbidity (NTU)
Yuma, AZ	8.06	1157	11.29	1.89
Maricopa, AZ	6.87	1430	9.70	1.99
Edinburg, TX	7.95	1405	-	27.4
Uvalde, TX	6.96	568	-	1.15

Bacterial strains: In order to assess microbial log reductions, our research team followed the newly published joint EPA/FDA efficacy protocol for reduction of foodborne bacteria in agriculture water for preharvest (<https://www.fda.gov/media/140640/download>). This test protocol is used to determine the effectiveness of a product for inactivating foodborne bacteria in preharvest agricultural water. The test protocol specifically evaluates multi-strain cocktails of *Salmonella* and Shiga-toxigenic *Escherichia coli* (STEC), previously isolated from irrigation water and other foodborne outbreaks and were available in the Rock culture collection used for all bench-top assessment. *E. coli* TVS353, isolated from surface water, was also utilized as a non-pathogenic indicator organism. All cultures were stored at -80°C and were streaked onto non-selective media prior to inoculation and incubated at 37°C for 18 to 24 hours. Individual colonies were sub-cultured in non-selective broth, and washed, prior to inoculation of irrigation water. Cocktails described above were added to water samples (1 L) to reach a final concentration described in the protocol of 10^9 - 10^{10} CFU/mL. For each water source, two temperatures and one pH value were evaluated. One set of water samples per pH (pH 8.4) at 12°C and the other at 32°C were equilibrated for at least 30 minutes prior to evaluation.

Benchtop water treatment: Laboratory-based water treatments focused on peroxyacetic acid (PAA) and calcium hypochlorite. Specific treatments included the following: Accu-Tab® – calcium hypochlorite and Sanidate® 12.0 Peroxyacetic Acid – PAA. Each product currently has an EPA pesticide label for preharvest water treatment to control for plant pathogens or to prevent fouling of irrigation systems. A total of two (2) product dilution rates of PAA (6 and 8

ppm residual PAA), and calcium hypochlorite (2 and 4 ppm free chlorine) were evaluated. Appropriate quenching reagents were used for each sanitizer; Sodium Metabisulfite (SMBS) for PAA and Hydrogen Peroxide (H₂O₂) and Sodium Thiosulphate for Calcium Hypochlorite treatments. All pre- and post-treated water samples were plated on appropriate selective media(s) and incubated at organism specific temperatures according to the EPA protocol.

The following figure (**Figure 1**) depicts results of the benchtop experiments for all water sources, sanitizer, temperature and pH combinations evaluated in this study. All experiments were evaluated in triplicate and standard error represented. It is important to note that a 1-minute contact time is prescribed in the EPA protocol. As a result of this research, the question has been raised as to if the contact time of 1 minute is appropriate for Agricultural Water uses, or if an extended contact time would be a more appropriate representation of what actually occurs in the field. **Figure 2** represents an extended contact time from 1 minute to 5 minutes in an effort to increase log-reductions of *E. coli* bacteria under the influence of PAA. It is easily noted that increasing the contact time from 1 to 5 minutes resulted in significant increases in log reduction values across all water sources and residual PAA values.

Figure 1. Log Reduction Values of EPA/FDA *E. coli* STEC 7-Strain Cocktail (values of 6 and 8 ppm represent PAA while values of 2 and 4 ppm represent residual free chlorine treatments).

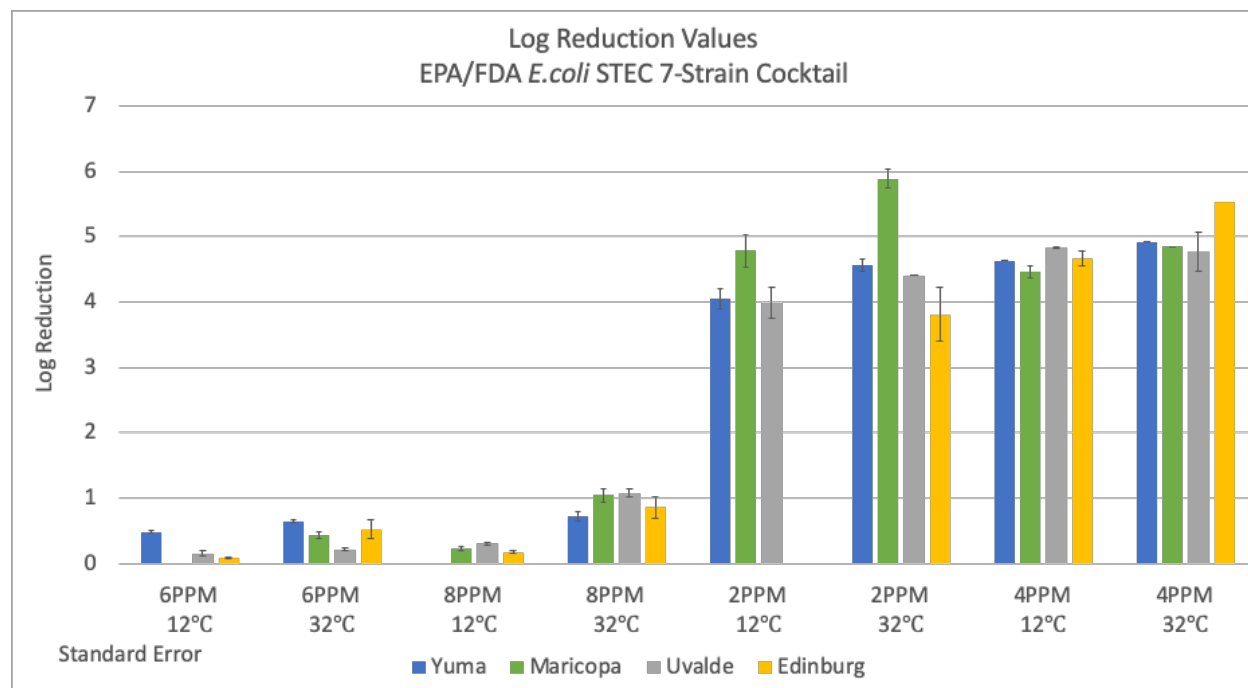
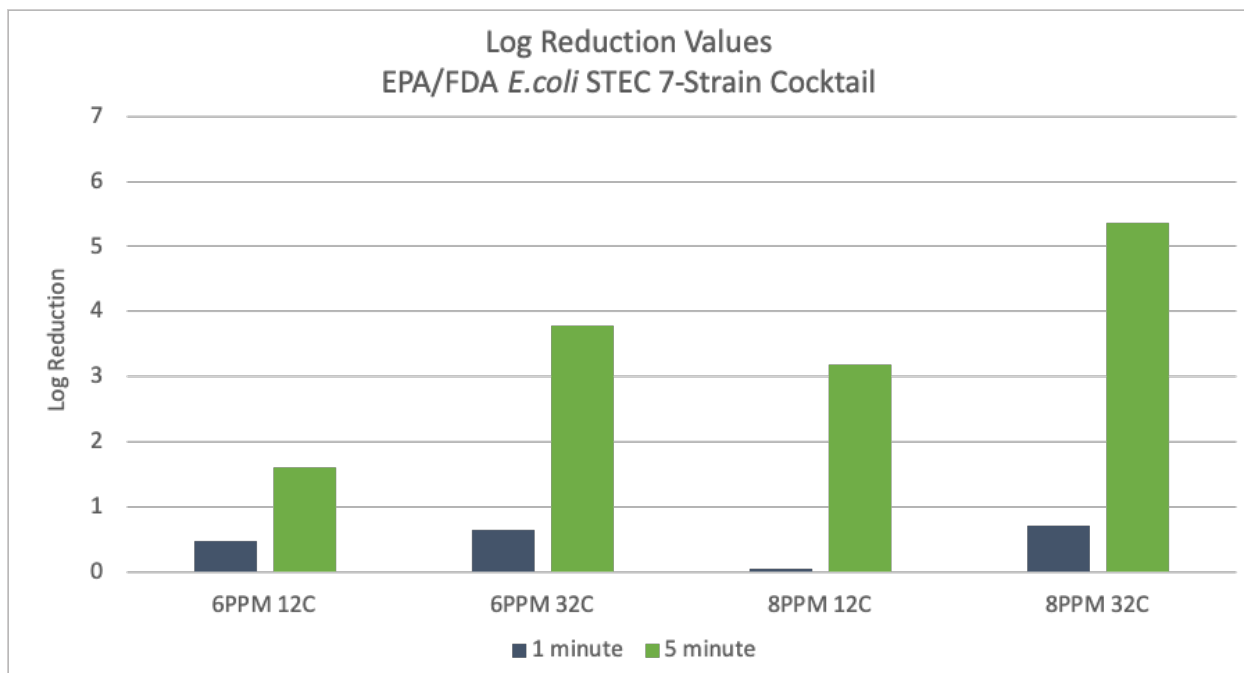


Figure 2. Peroxyacetic Acid (PAA) Log Reduction Values of EPA/FDA *E. coli* STEC 7-Strain Cocktail when comparing a 1-minute and 5-minute contact time.



Objectives 2 and 3: Field-scale water treatment analysis. Following the laboratory-scale benchtop experiments, the research team used data collected in bench-top evaluations to optimize commercial field-scale water treatment in each of the four locations being evaluated.

The treatment systems/methods were installed adjacent to collective surface water irrigation source in each of the four field locations. This allowed the research team to evaluate multiple treatment strategies using a common water source for comparison. Irrigation pumps were set up to allow for separate injection or gravity feed of either the Accu-Tab® – calcium hypochlorite or Sanidate® Peroxyacetic Acid – PAA. The Ag Partners Southwest Sunburst 12-40 UV Water Treatment System was installed inline on-farm adjacent to the irrigation water source at the Maricopa, AZ location only, and allowed the research team to access the water both pre- and post-treatment prior to field irrigation. All three antimicrobial water treatments in addition to raw water controls were supplied to 0.5–1-acre leafy greens (romaine, spinach, and mint) plots in addition to a raw water control. Irrigation water samples from the background water source pre-treatment and post-treatment samples from select sprinklers (first and last sprinkler heads) along the length of the irrigation system were collected. Water samples (water pre- and post-treatment) were collected in 1-L sterile wide-mouth polypropylene containers and transported on ice back to the laboratory to begin analysis with 6 hours of collection. Appropriate quenching reagents for each sanitizer, Sodium Metabisulfite (SMBS) for PAA and Hydrogen Peroxide (H₂O₂) and Sodium Thiosulphate for Calcium Hypochlorite treatments, were added to the

sterile bottles prior to the experiment. All water samples were collected using aseptic technique and stored in coolers on ice until sample processing.

Treated irrigation water samples were collected immediately after system start up (pressurization), and then every 5 to 20 minutes for up to 2 hours from the three locations (canal, first, and last sprinkler heads). All samples were assayed within 6 hours according to Method 9223 B., *Enzyme Substrate Coliform Test* (Standard Methods, 2012). Physical and chemical parameters were collected on-site at the beginning of the trial using a Hach meter (HQ 40d multiprobe; Loveland, CO) to measure pH, dissolved oxygen (DO), water temperature, air temperature, and electrical conductivity (EC). Turbidity (Hach 2100Q Portable Turbidimeter; Loveland, CO) was also measured in the laboratory. It should also be noted that all sampling events included both positive and negative controls to ensure confidence in sample results.

The following figures (**Figures 3–30**) provide results of PAA, Calcium Hypochlorite (CL), Chlorine Dioxide (CLO₂) (Maricopa only) and UV (Maricopa only) analysis across the Southwest region for both generic *E. coli* bacteria and total coliform bacteria at the first and last sprinkler head collection locations. All blue bars indicate bacterial concentrations in the background or ditch (pre-treatment) and all red bars indicate bacterial concentrations collected at the first or last sprinkler head (post-treatment).

Figure 3. PAA Effectiveness Against Total Coliform Bacteria First Sprinkler Head - Yuma

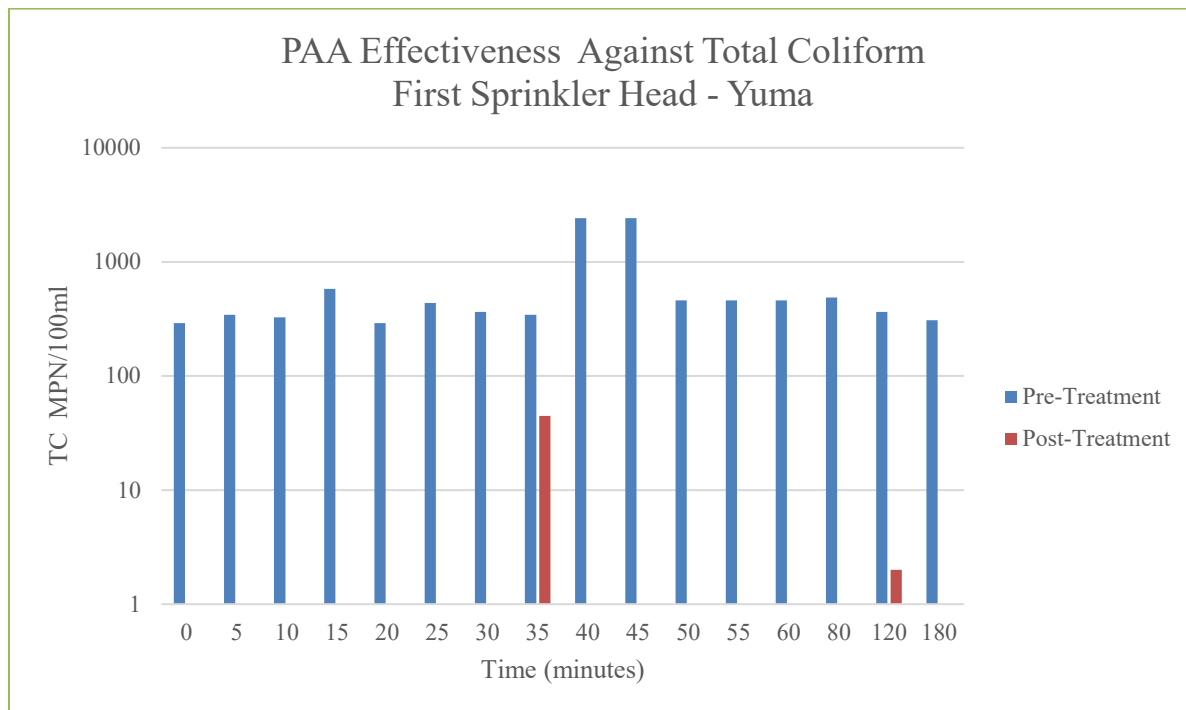


Figure 4. PAA Effectiveness Against Total Coliform Bacteria Last Sprinkler Head - Yuma

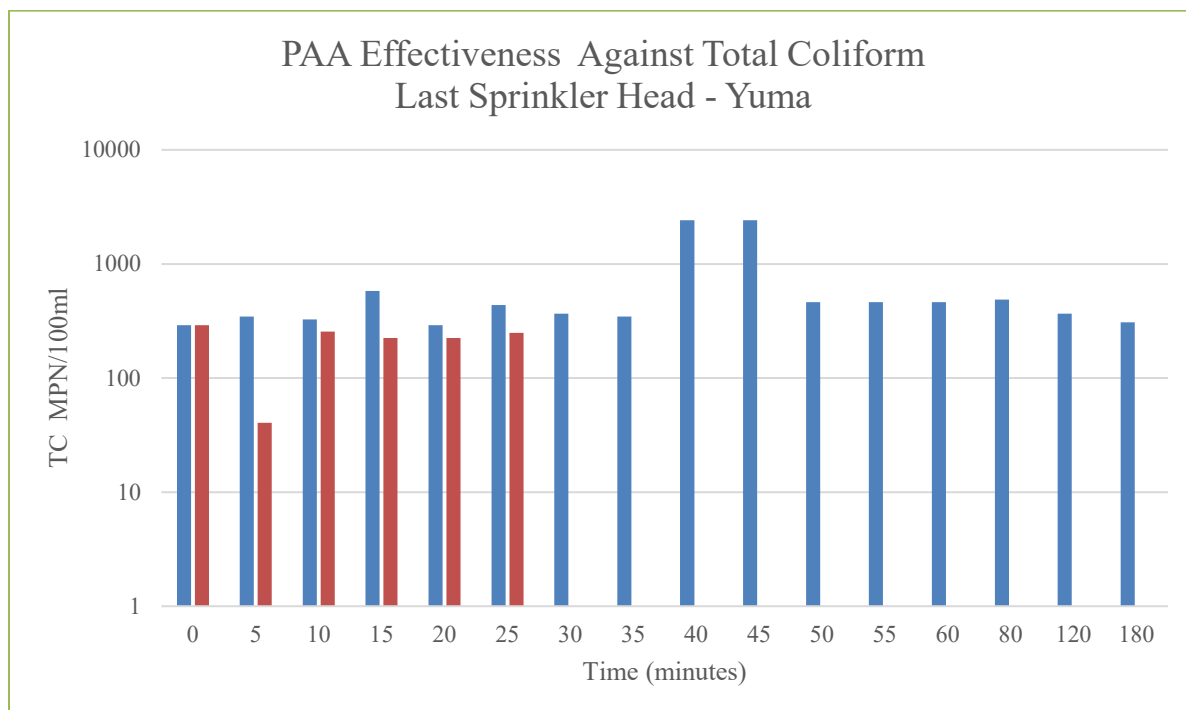


Figure 5. PAA Effectiveness Against *E. coli* Bacteria First Sprinkler Head - Yuma

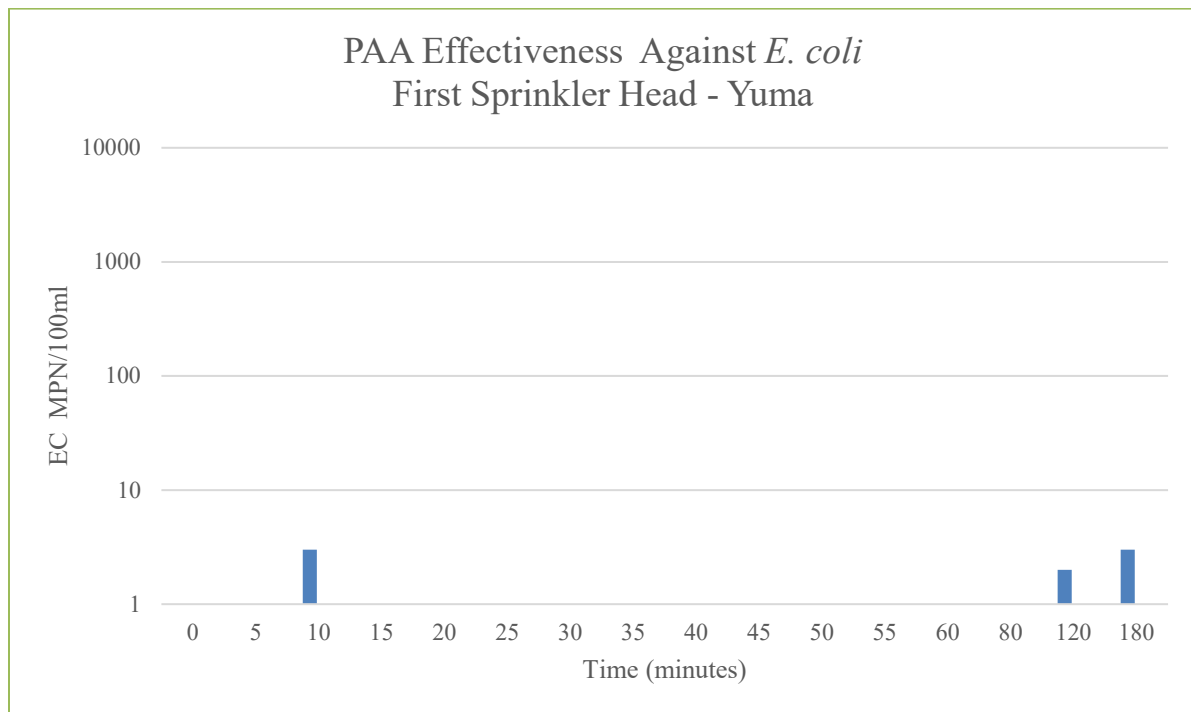


Figure 6. PAA Effectiveness Against *E. coli* Bacteria Last Sprinkler Head - Yuma

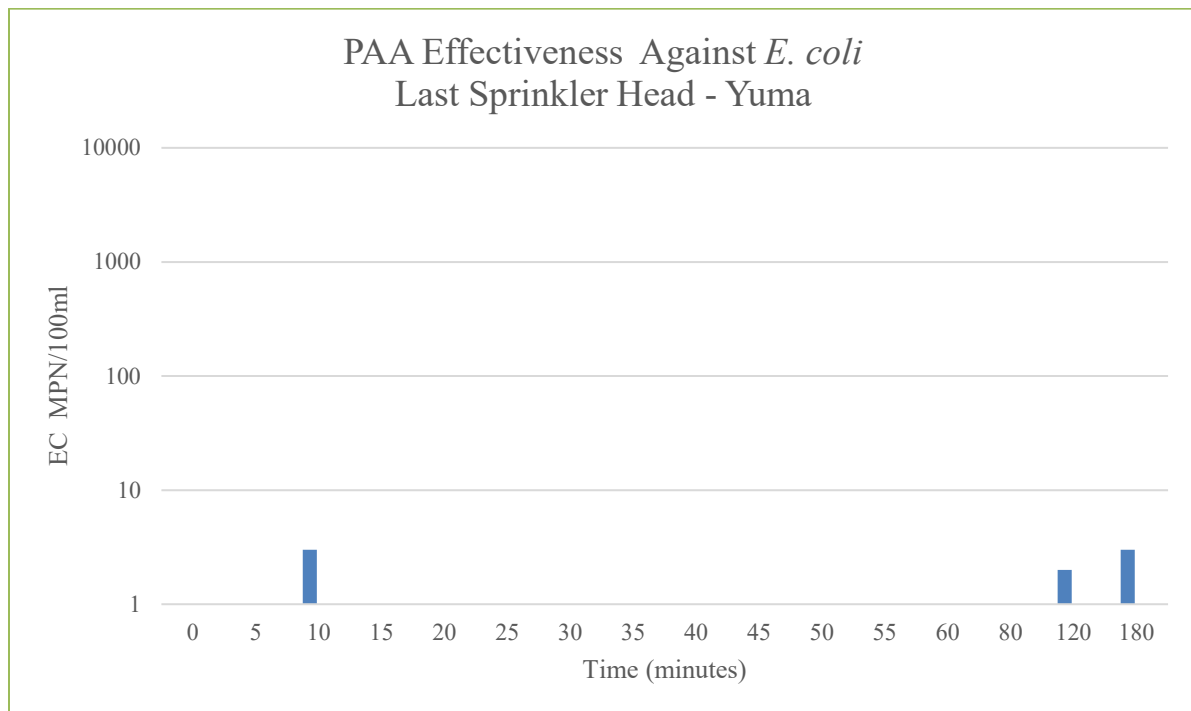


Figure 7. CL Effectiveness Against Total Coliform Bacteria First Sprinkler Head - Yuma

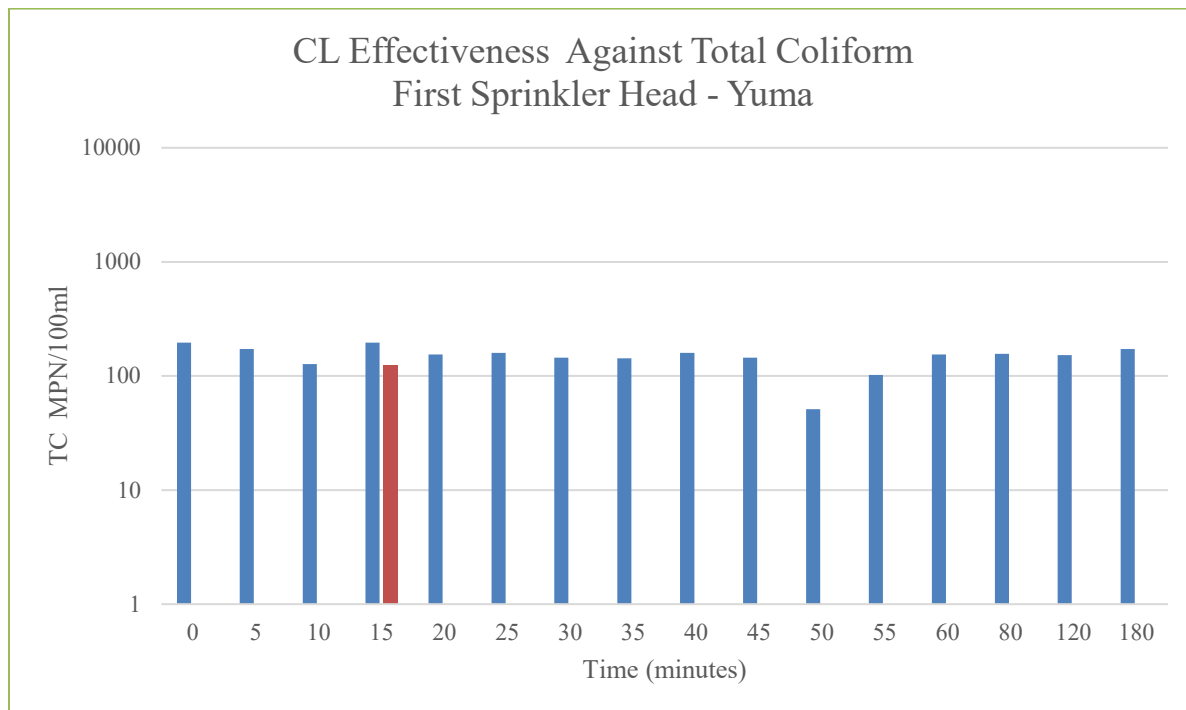


Figure 8. CL Effectiveness Against Total Coliform Bacteria Last Sprinkler Head - Yuma

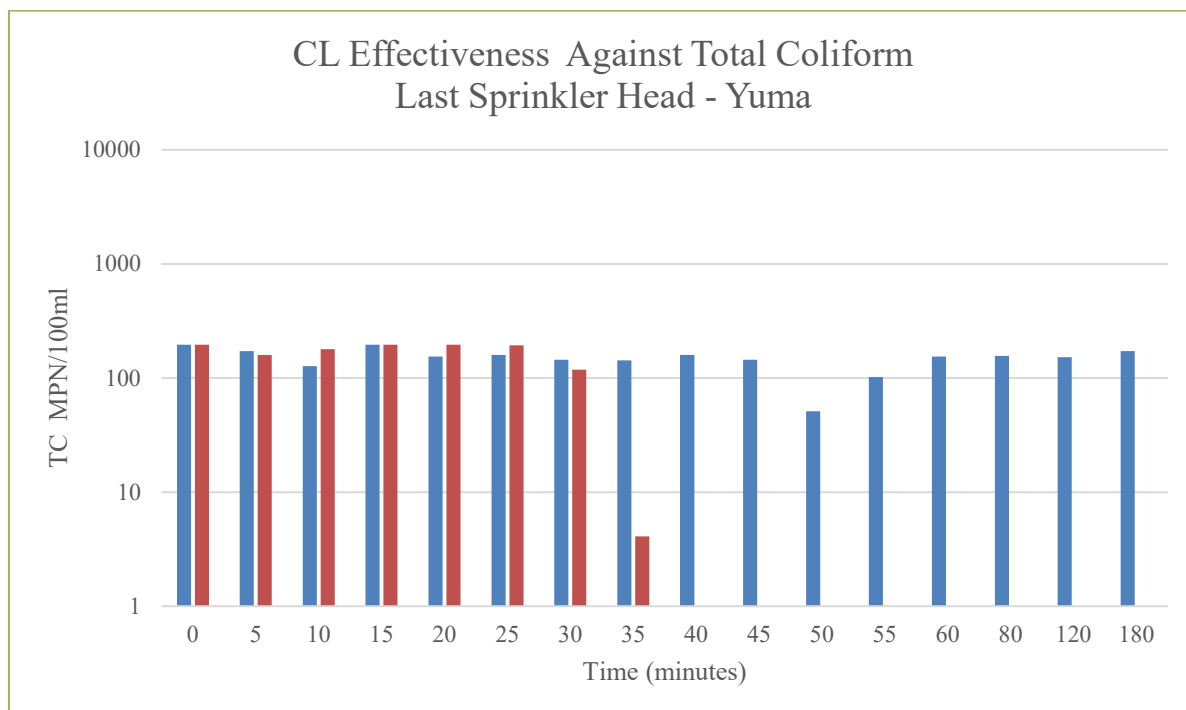


Figure 9. CL Effectiveness Against *E. coli* Bacteria First Sprinkler Head - Yuma

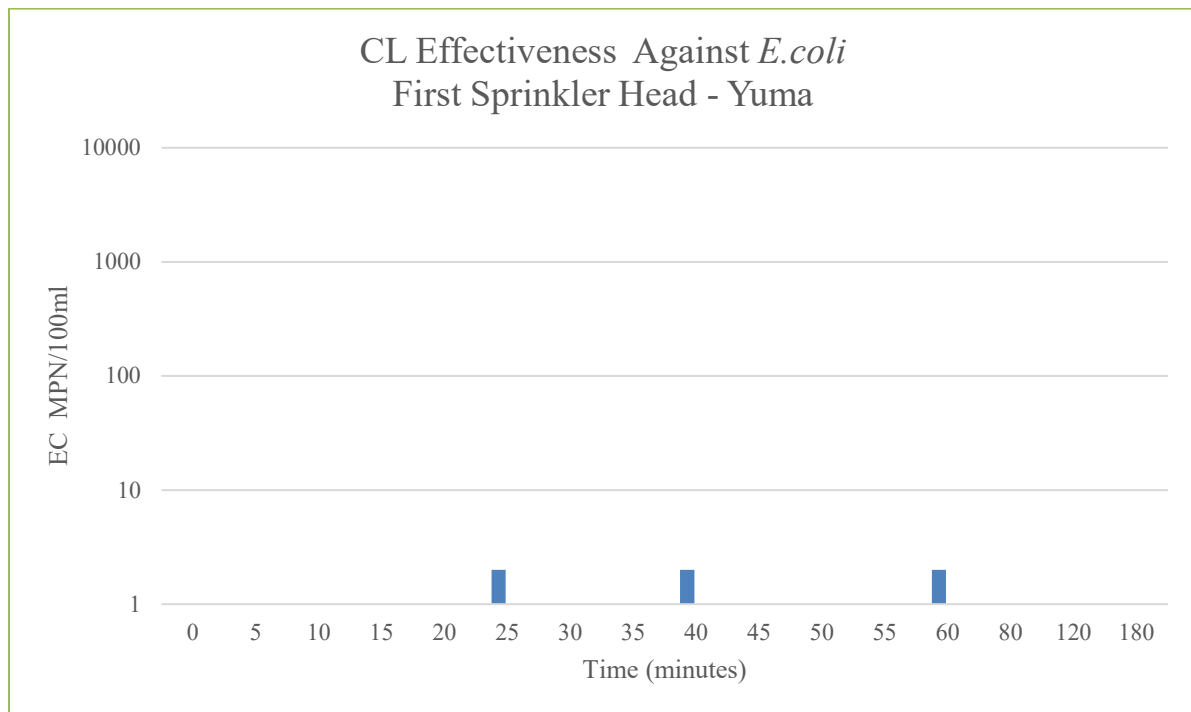


Figure 10. CL Effectiveness Against *E. coli* Bacteria Last Sprinkler Head - Yuma

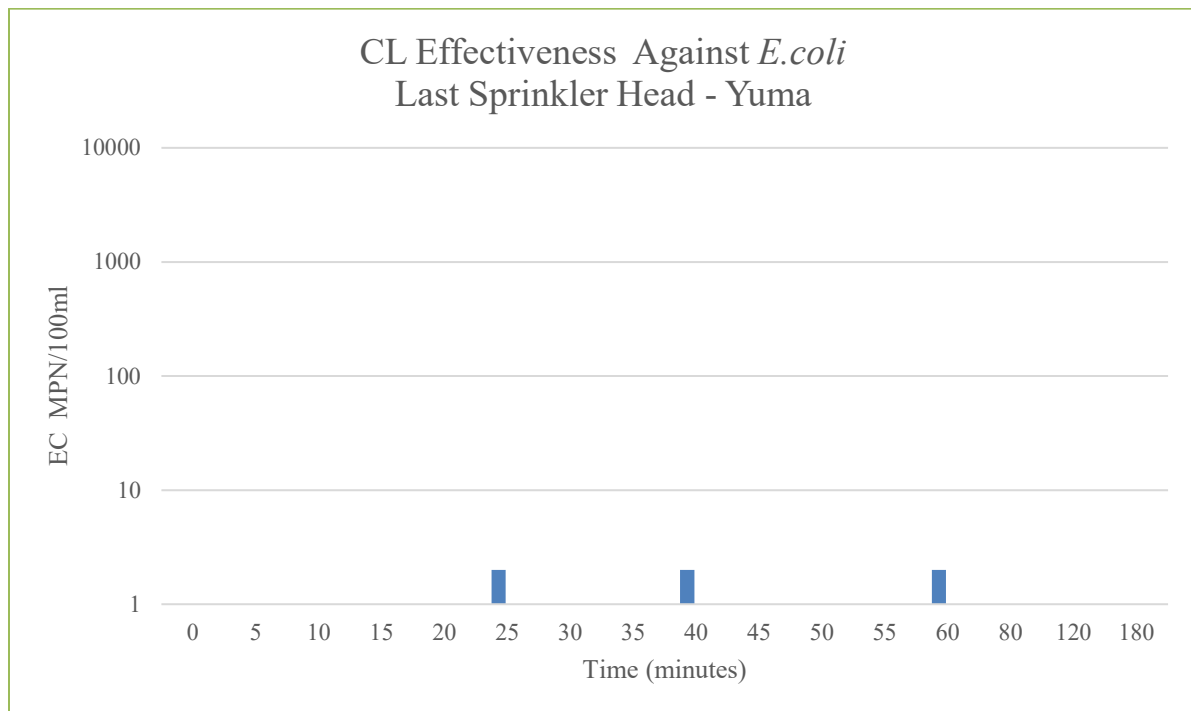


Figure 11. PAA Effectiveness Against Total Coliform Bacteria First Sprinkler Head - Maricopa

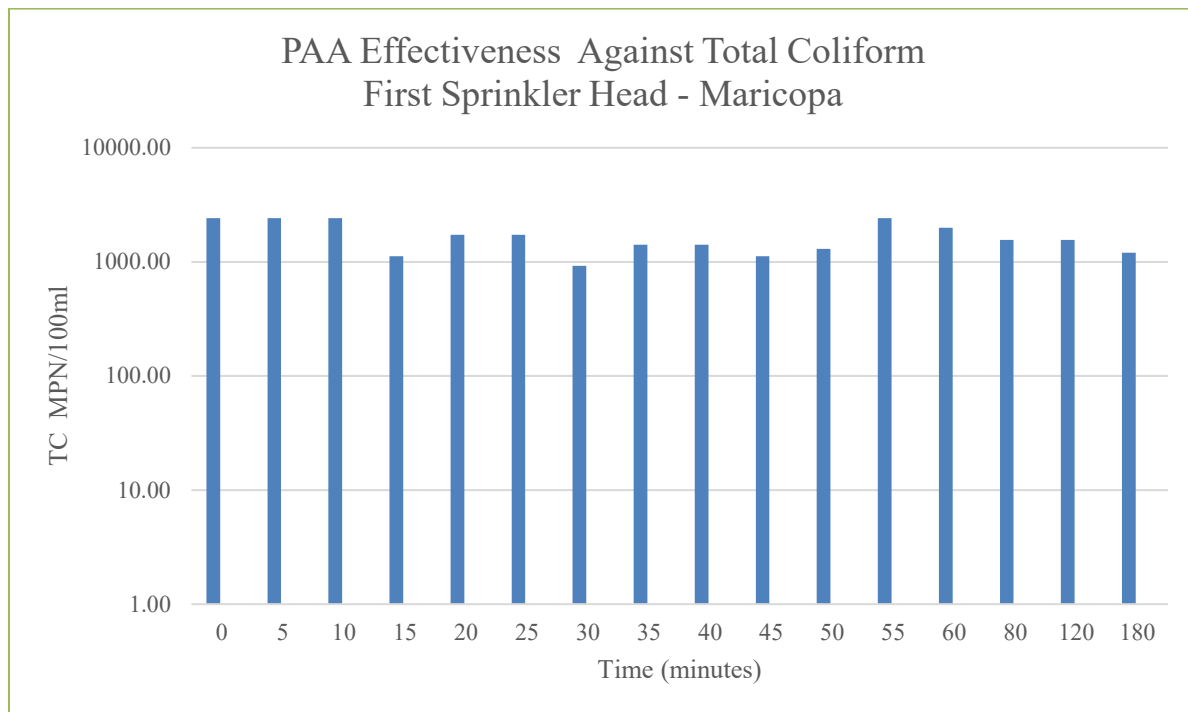


Figure 12. PAA Effectiveness Against Total Coliform Bacteria Last Sprinkler Head - Maricopa

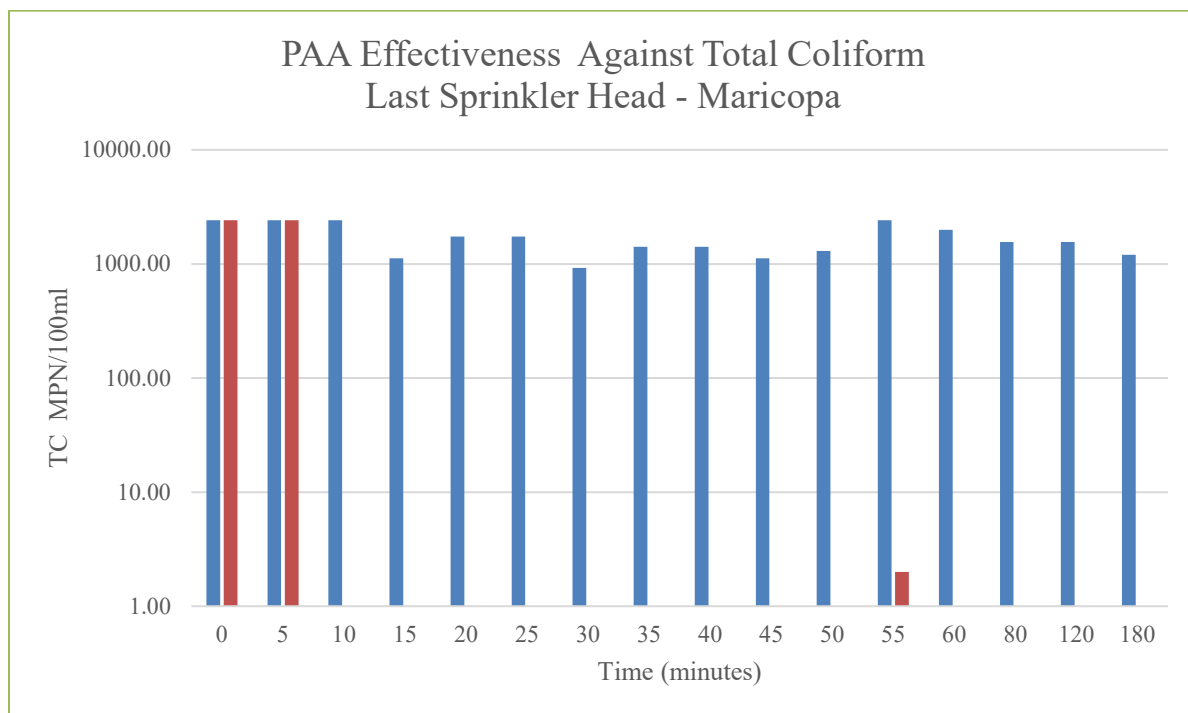


Figure 13. PAA Effectiveness Against *E. coli* Bacteria First Sprinkler Head - Maricopa

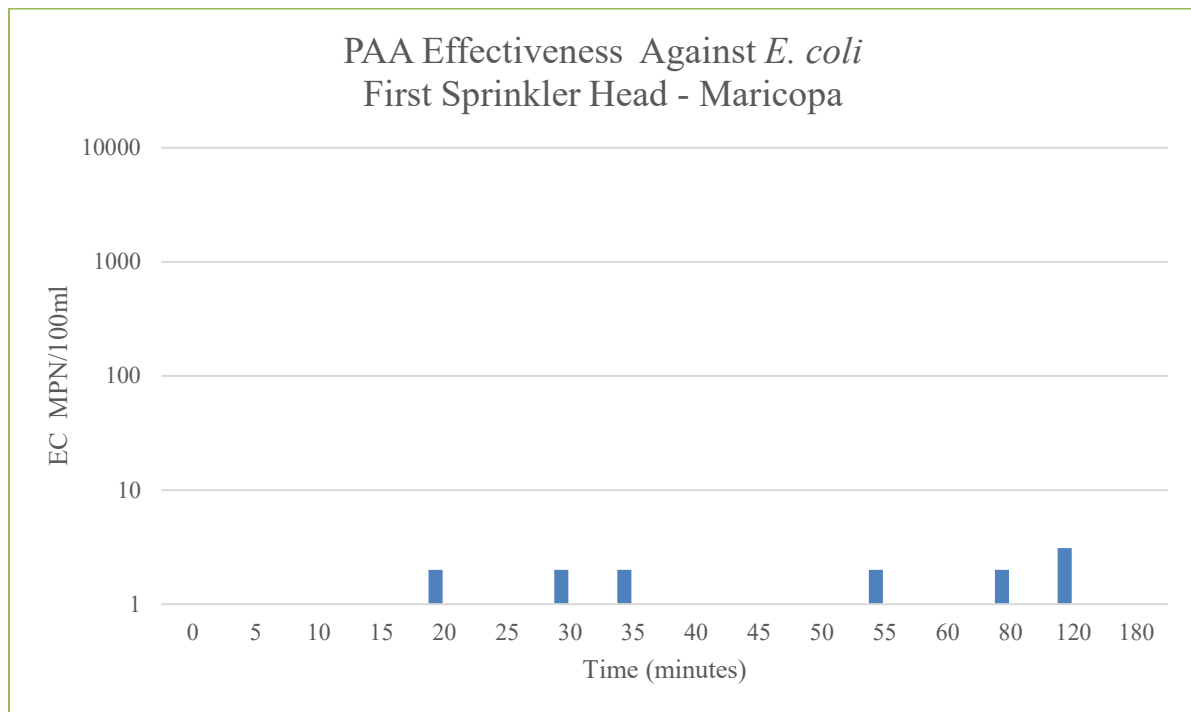


Figure 14. PAA Effectiveness Against *E. coli* Bacteria Last Sprinkler Head - Yuma

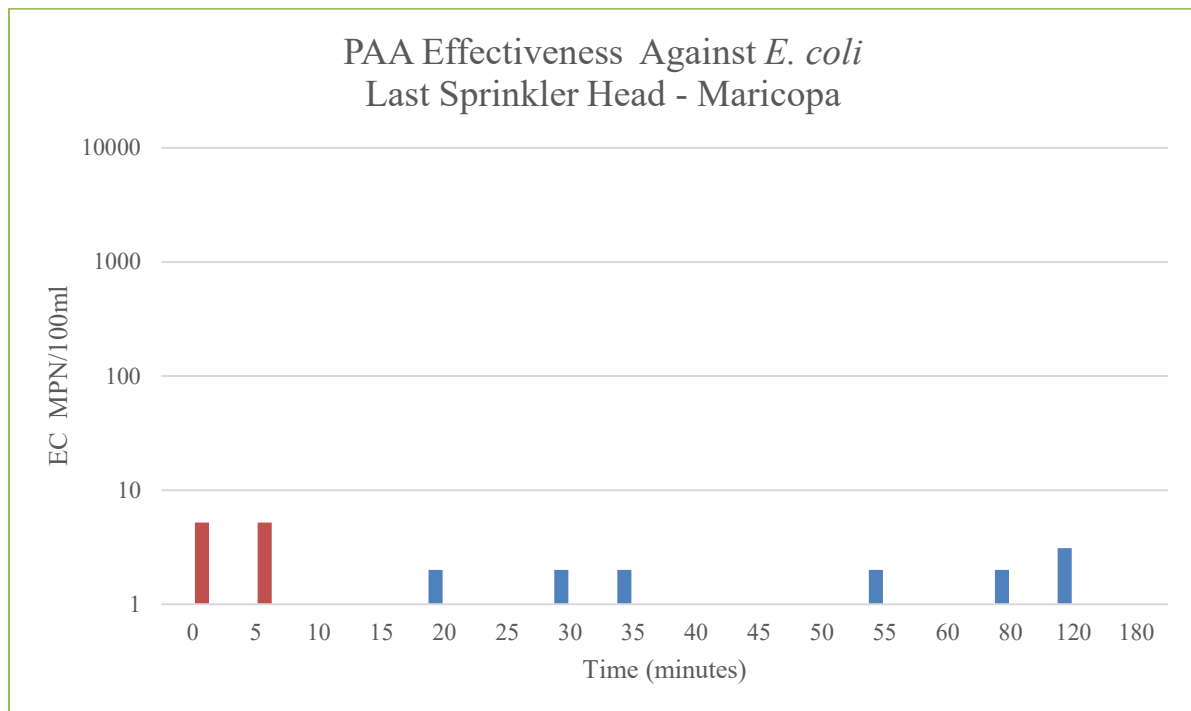


Figure 15. CLO2 Effectiveness Against Total Coliform Bacteria First Sprinkler Head - Maricopa

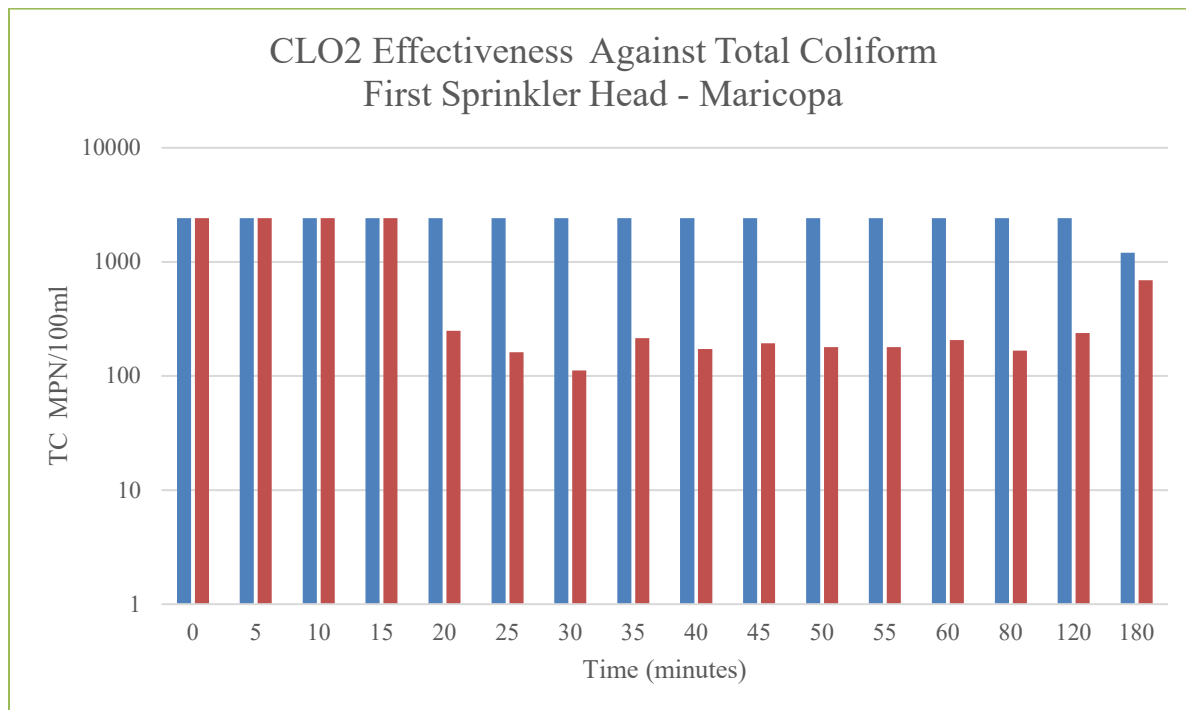


Figure 16. CLO2 Effectiveness Against Total Coliform Bacteria Last Sprinkler Head - Maricopa

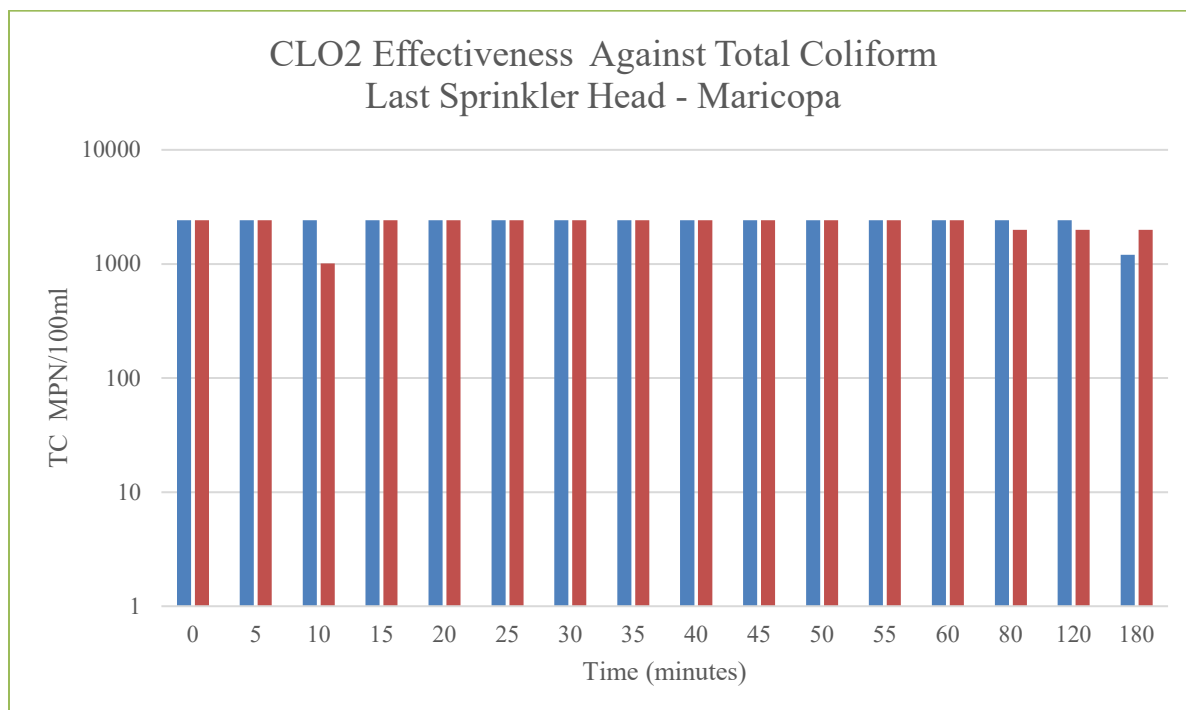


Figure 17. CLO2 Effectiveness Against *E. coli* Bacteria First Sprinkler Head - Maricopa

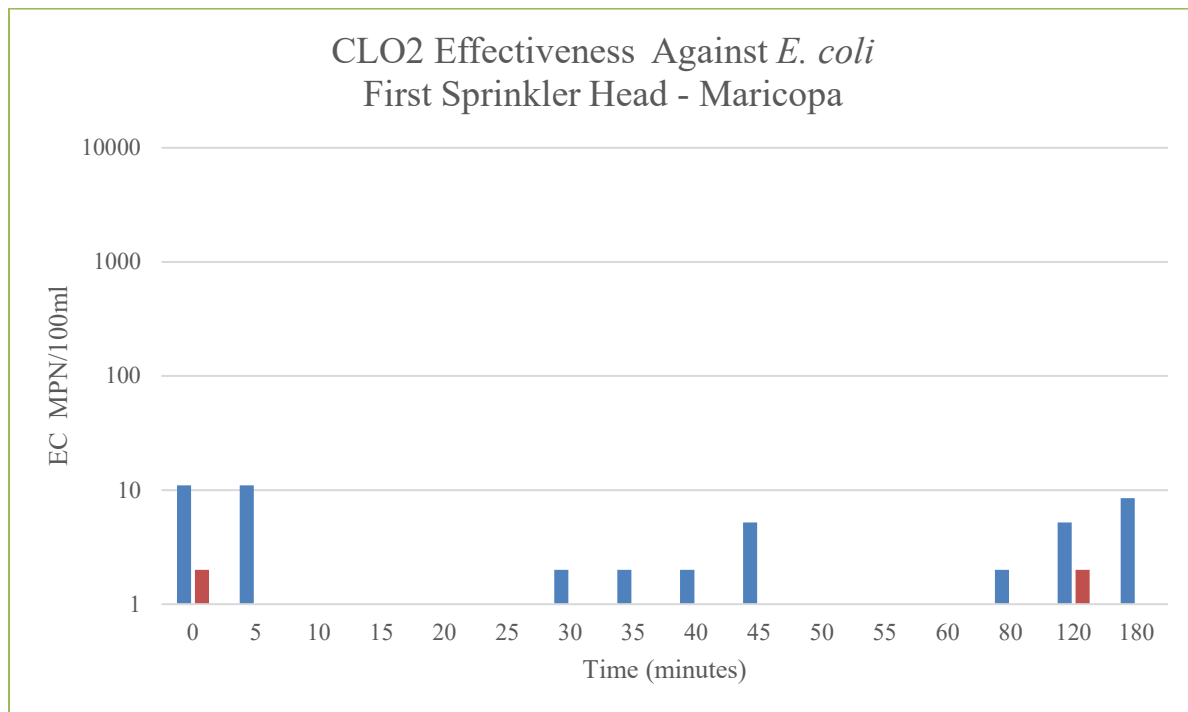


Figure 18. CLO2 Effectiveness Against *E. coli* Bacteria Last Sprinkler Head - Maricopa

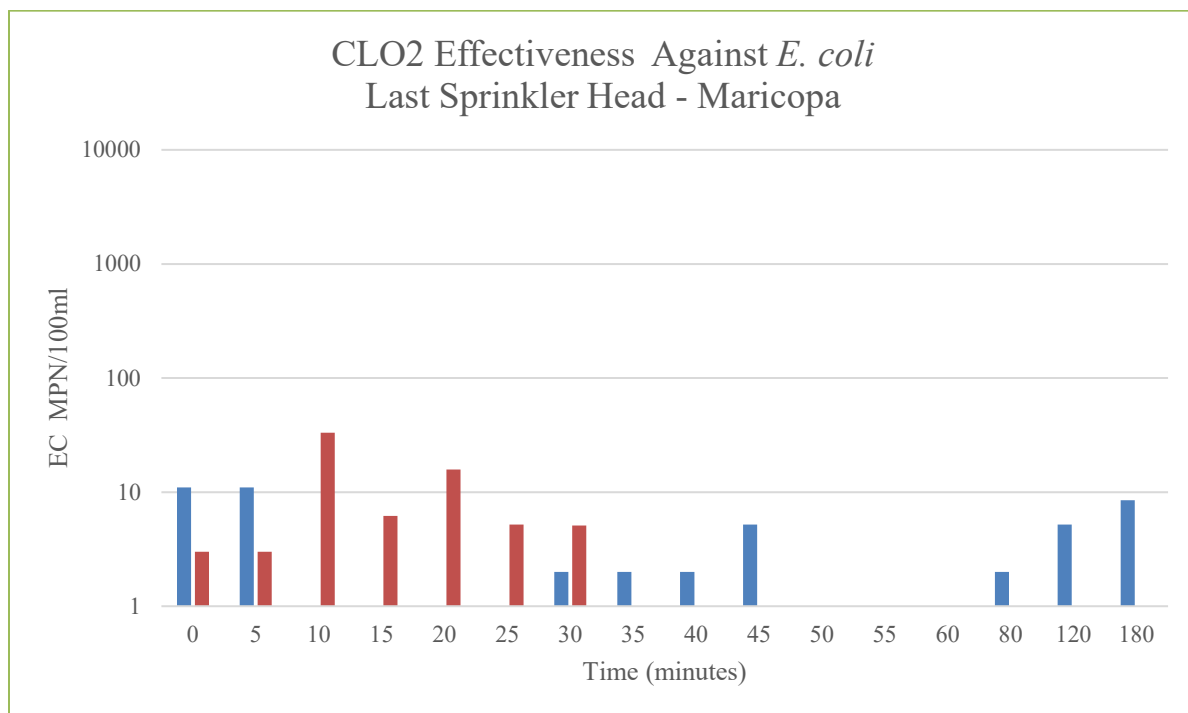


Figure 19. UV Effectiveness Against Total Coliform Bacteria First Sprinkler Head - Yuma

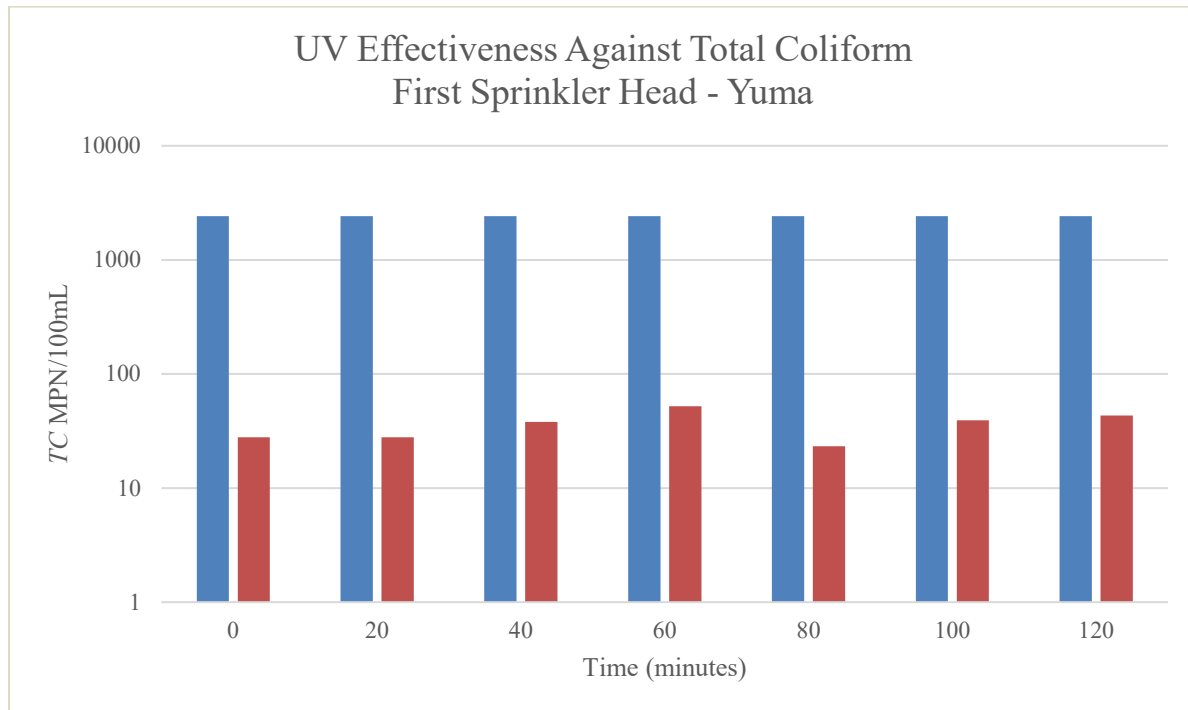


Figure 20. UV Effectiveness Against Total Coliform Bacteria Last Sprinkler Head - Yuma

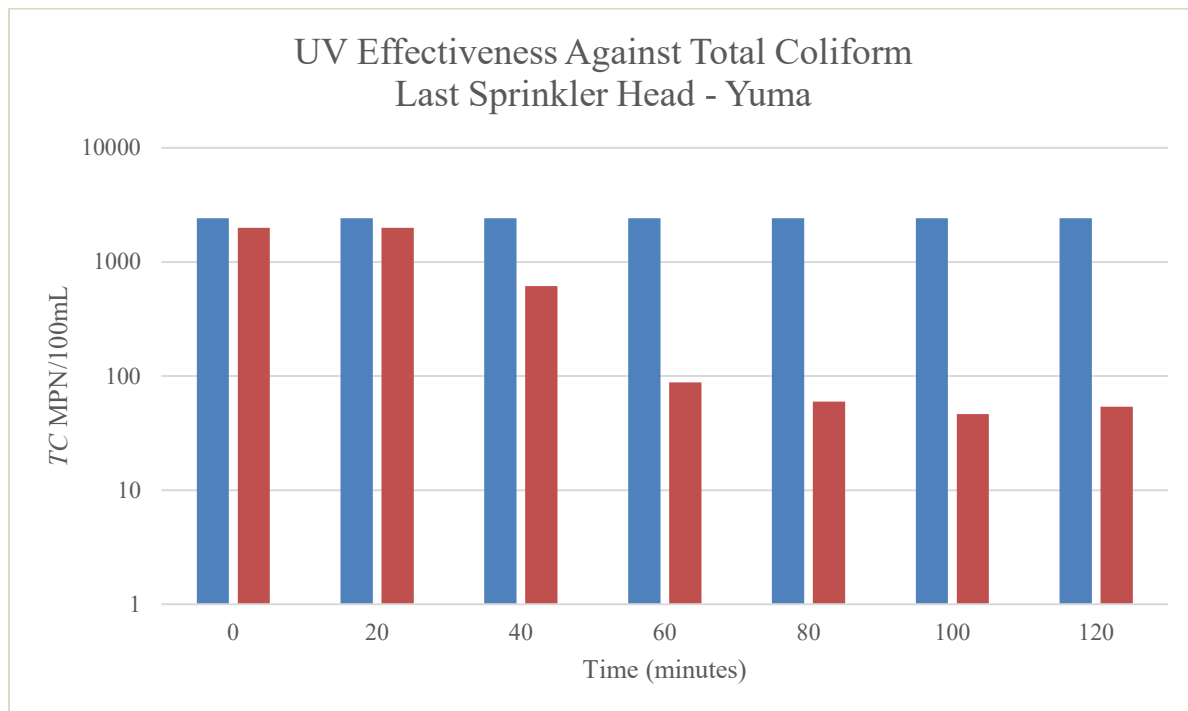


Figure 21. UV Effectiveness Against *E. coli* Bacteria First Sprinkler Head - Yuma

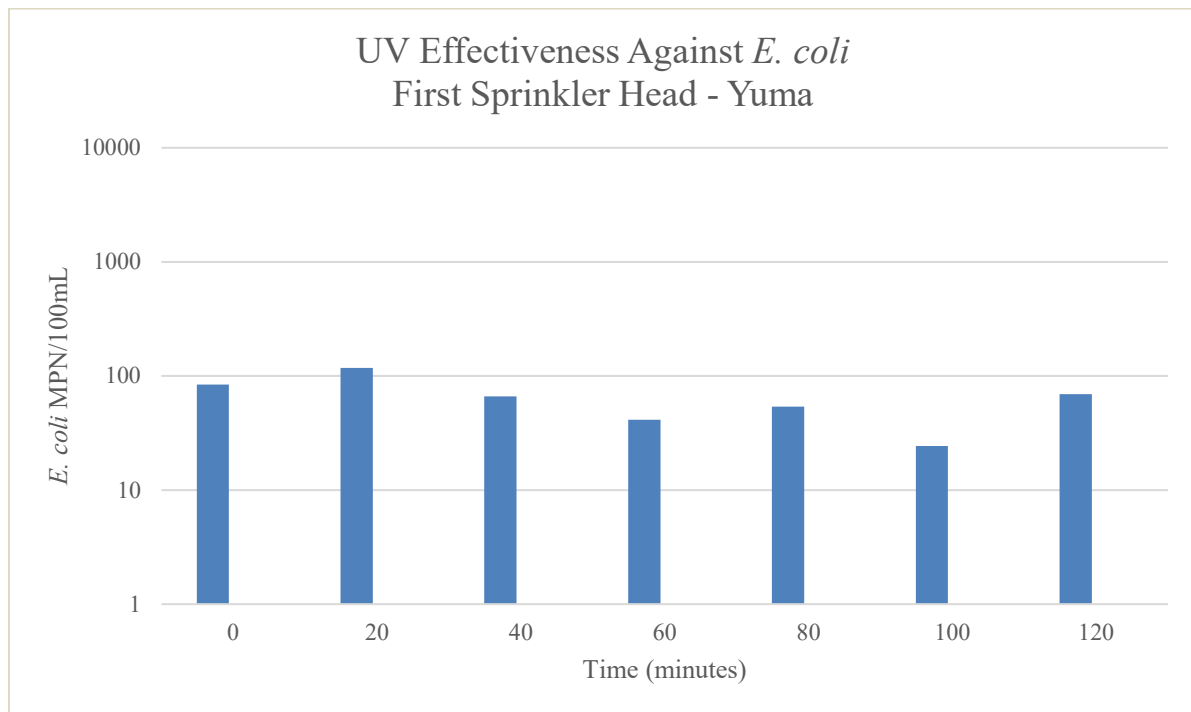


Figure 22. UV Effectiveness Against *E. coli* Bacteria Last Sprinkler Head - Yuma

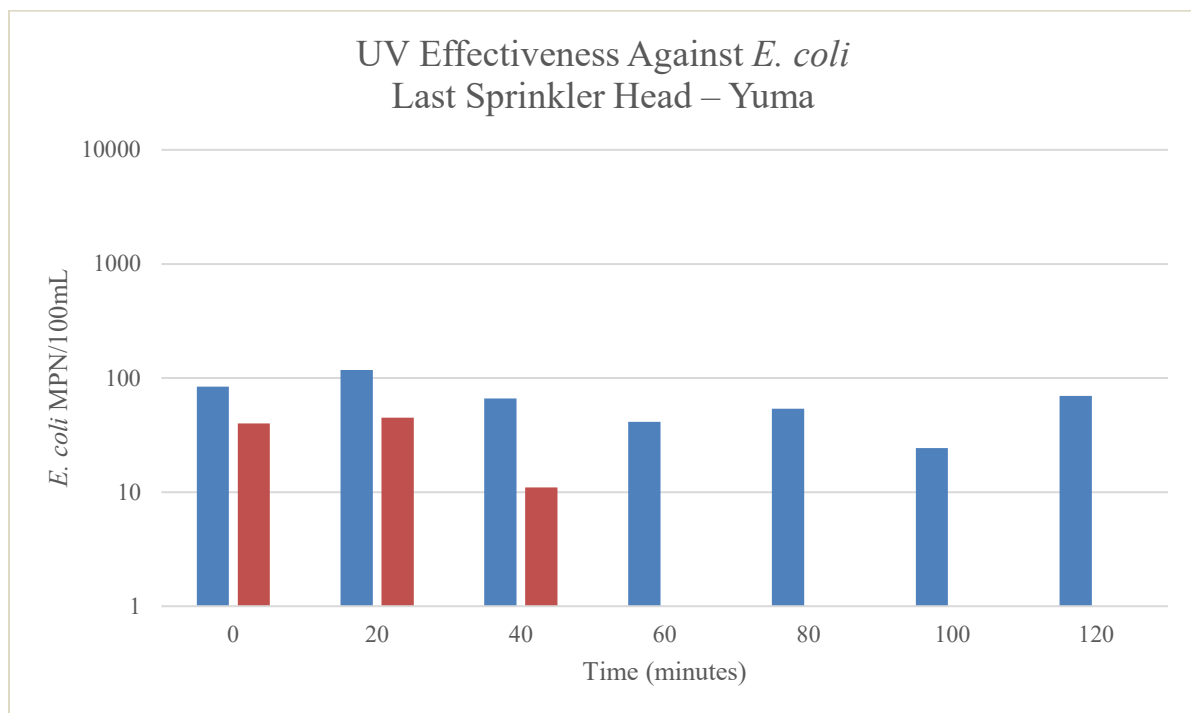


Figure 23. PAA Effectiveness Against Total Coliform Bacteria First Head – Rio Grande

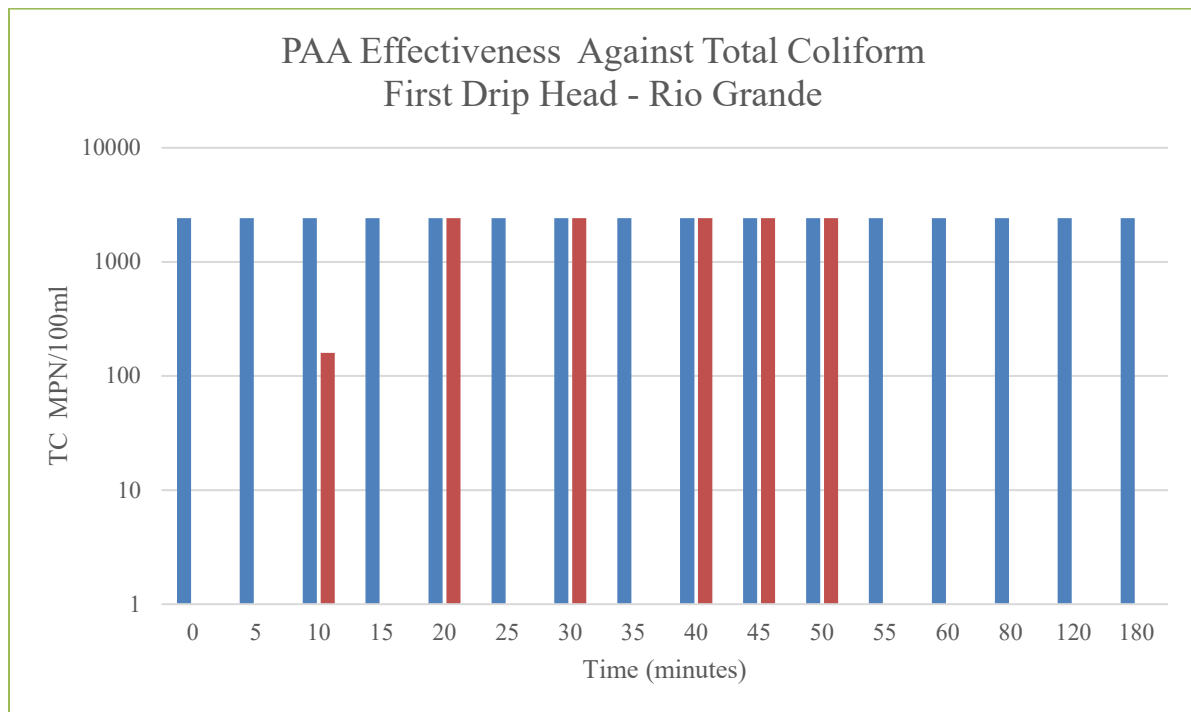


Figure 24. PAA Effectiveness Against Total Coliform Bacteria Last Head – Rio Grande

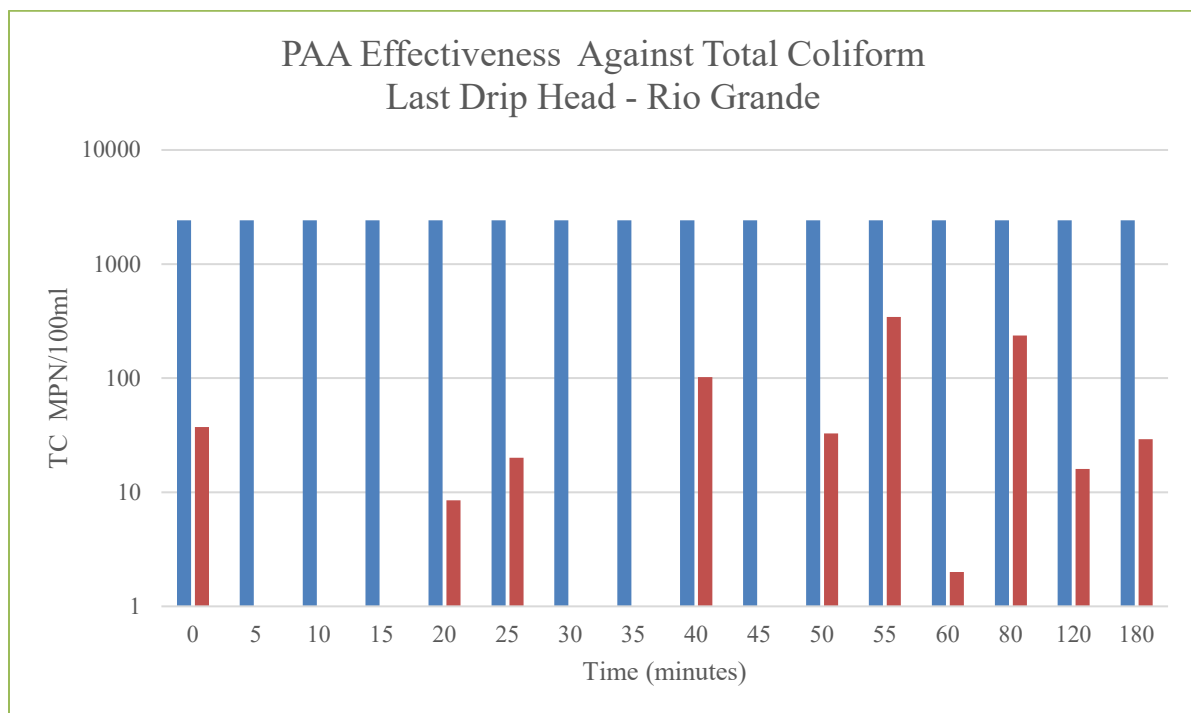


Figure 25. PAA Effectiveness Against *E. coli* Bacteria First Head – Rio Grande

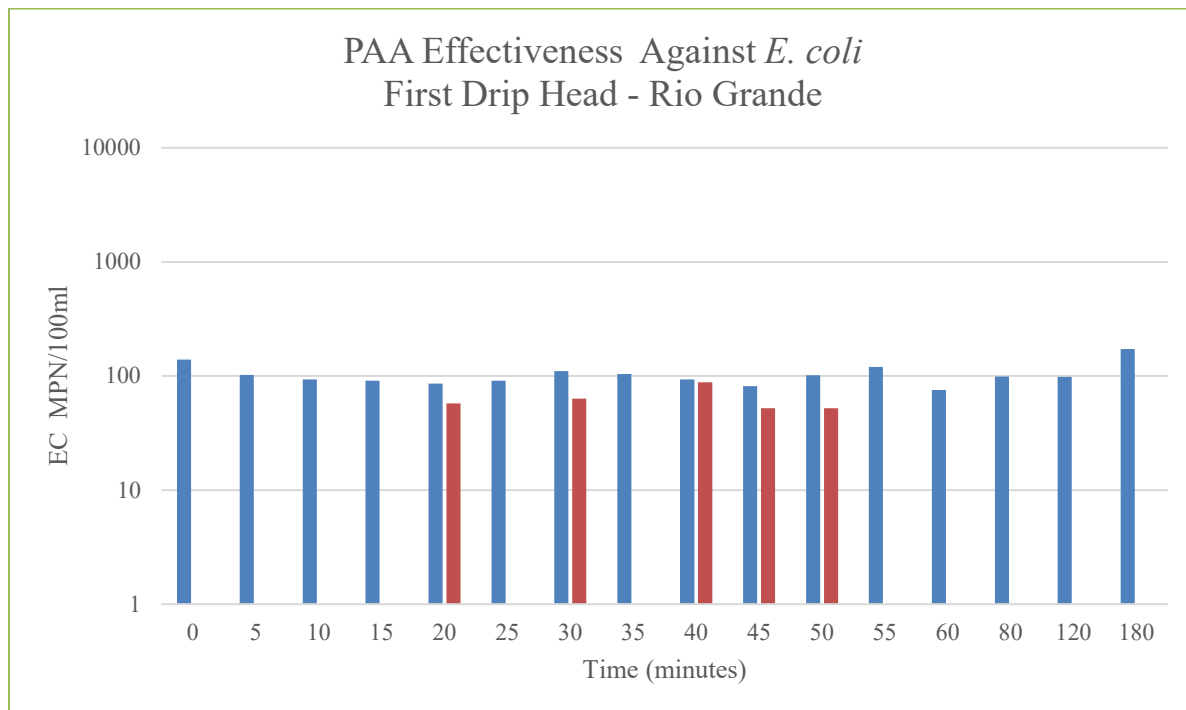


Figure 26. PAA Effectiveness Against *E. coli* Bacteria Last Head – Rio Grande

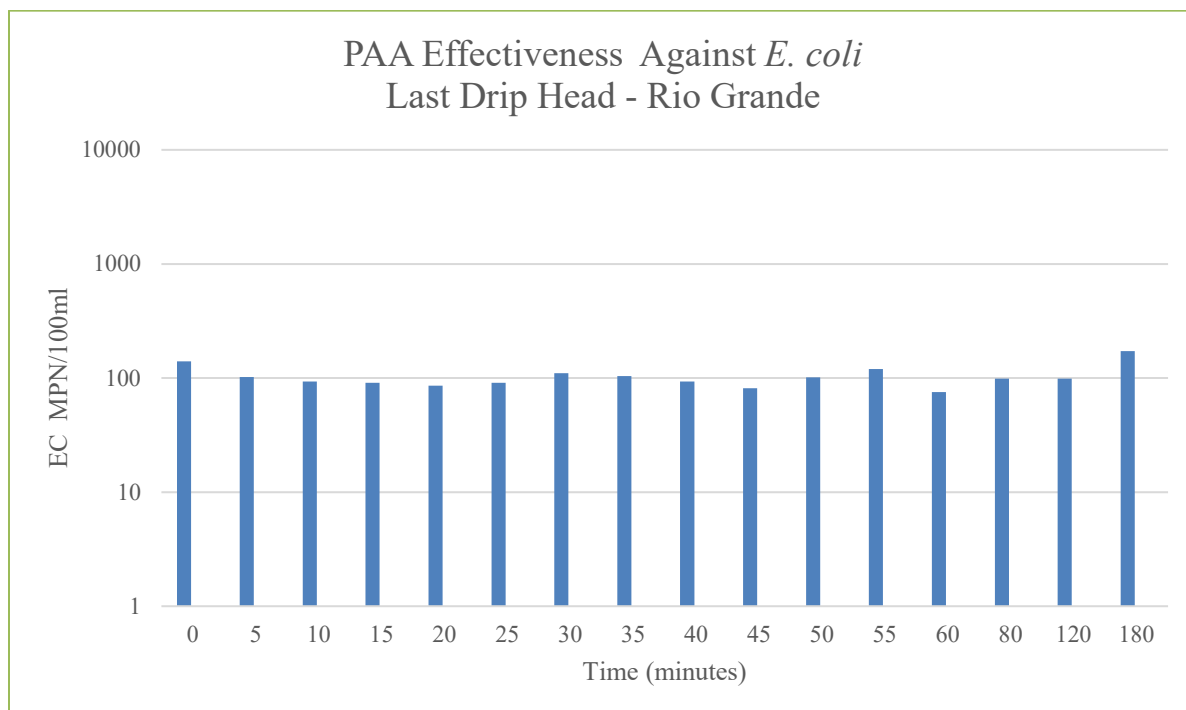


Figure 27. CL Effectiveness Against Total Coliform Bacteria First Head – Rio Grande

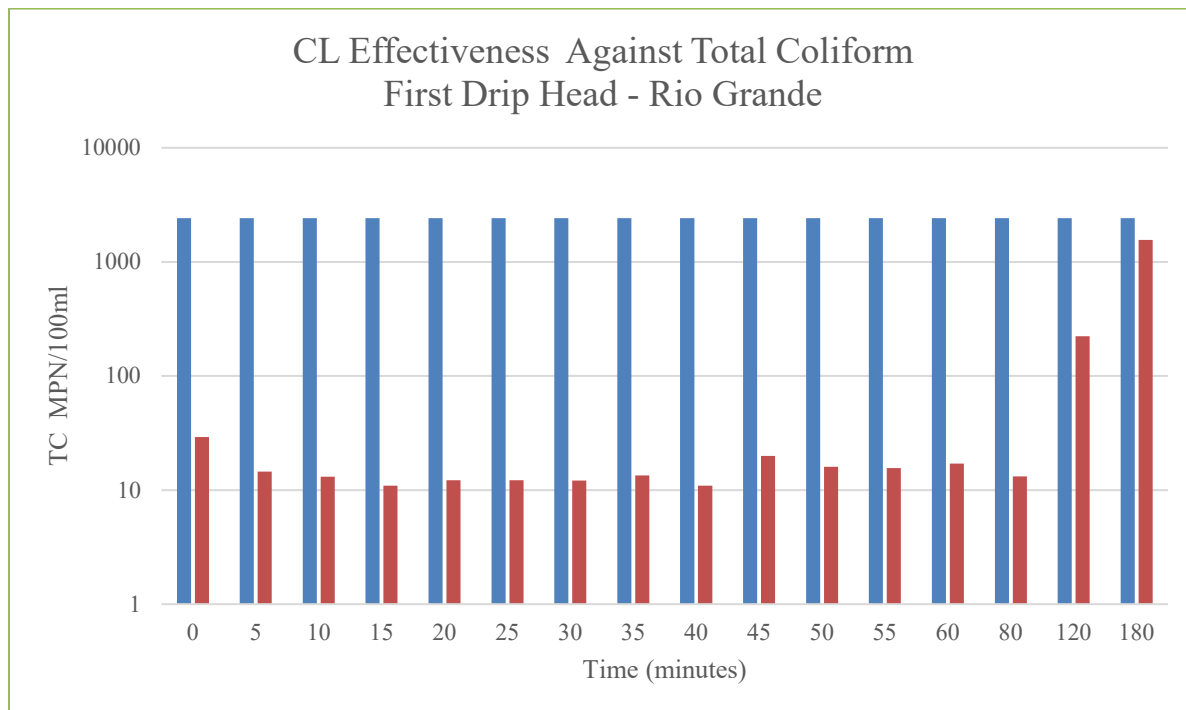


Figure 28. CL Effectiveness Against Total Coliform Bacteria Last Head – Rio Grande

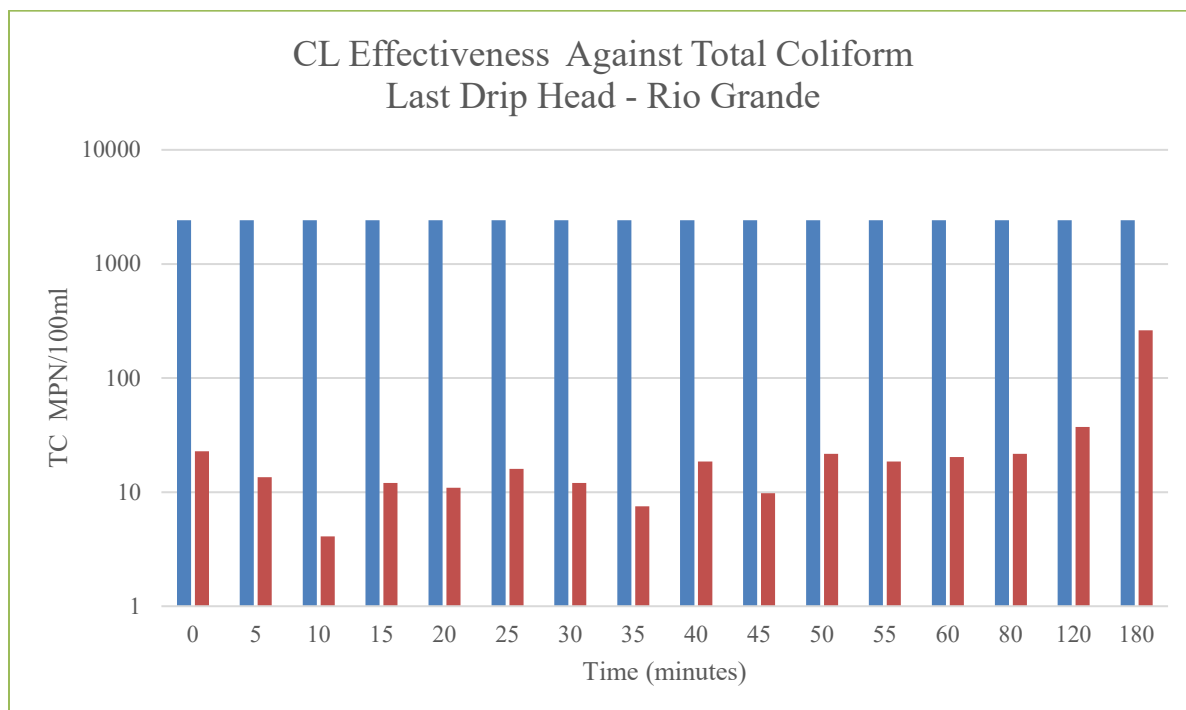


Figure 29. CL Effectiveness Against *E. coli* Bacteria First Head – Rio Grande

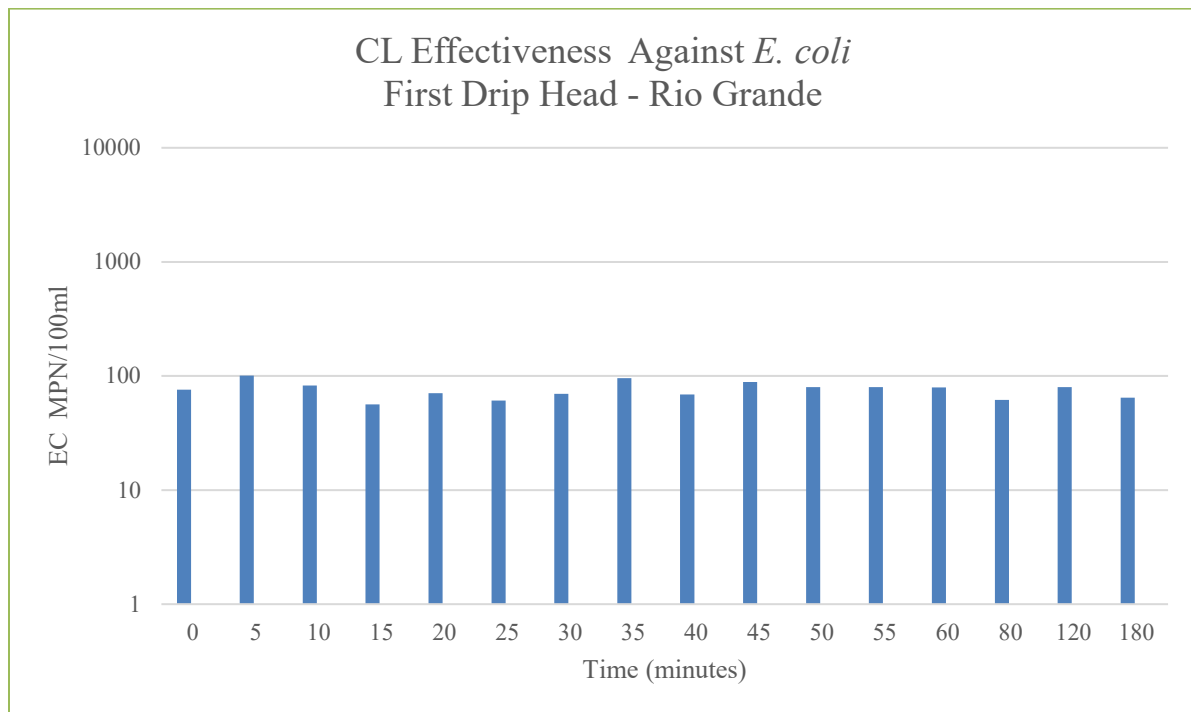
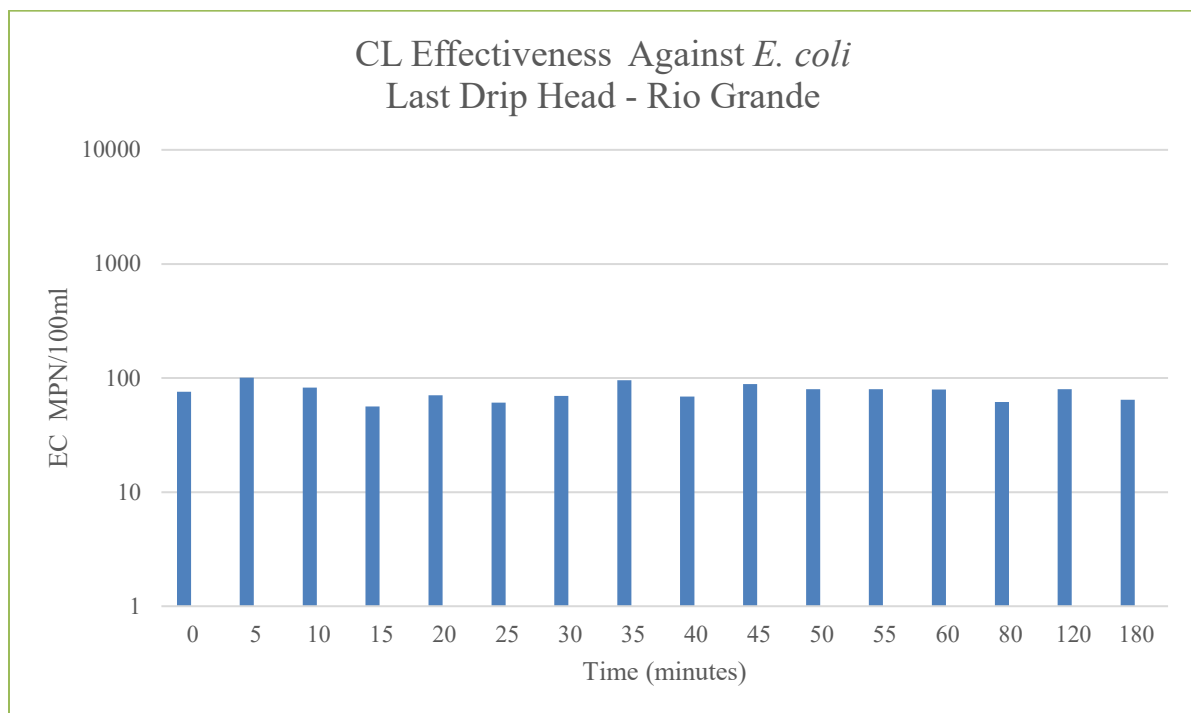


Figure 30. CL Effectiveness Against *E. coli* Bacteria Last Head – Rio Grande



At the onset of the project, the team anticipated conducting full-scale water treatment trials exactly mimicking water treatment set up in each Arizona and Texas locations. However, because the Uvalde, TX, ranch relied on pivot irrigation, the research team decided to modify the agricultural water treatment approach and conduct a series of side-dress/overhead water events to mimic agricultural water treatment in a tank mix used for fertigation. Each of the two water treatment chemistries were dosed into an overhead sprayer at the predetermined dose (8 ppm for PAA and 2 ppm for CL). Treated water samples were collected according to the University of Arizona SOP and assayed within 6 hours according to Method 9223 B., Enzyme Substrate Coliform Test (Standard Methods, 2012). Results are shown in **Tables 3 and 4** below. Physical and chemical parameters were collected on-site at the beginning of the trial using a Hach meter (HQ 40d multiprobe; Loveland, CO) to measure pH, dissolved oxygen (DO), water temperature, air temperature, and electrical conductivity (EC). Additionally, turbidity (Hach 2100Q Portable Turbidimeter; Loveland, CO) was also measured in the laboratory.

Table 3. *E. coli* and total coliform counts in agricultural water used for spinach irrigation

log MPN/100 ml \pm SEM (N = 36)		
Treatment ^a	<i>E. coli</i>	Total coliform
Control	$<0.0 \pm 0.00A^b$	$2.8 \pm 0.08A$
PAA	$<0.0 \pm 0.00A$	$<0.0 \pm 0.00C$
Cl	$<0.0 \pm 0.00A$	$1.3 \pm 0.12B$

^a Control, non-treated water; PAA, peroxyacetic acid (8 mg/liter); Cl, calcium hypochlorite (2 mg/liter free chlorine). ^b Within columns, means followed by same letter are not different ($p < 0.05$).

Table 4. *E. coli* and total coliform counts in soil collected from spinach fields irrigated with agricultural water subjected to different antimicrobial treatments.

log CFU/g \pm SEM (N = 24)		
Water treatments ^a	<i>E. coli</i>	Total coliforms
Control	$<1.0 \pm 0.00A^b$	$3.3 \pm 0.21A$
PAA	$<1.0 \pm 0.00A$	$2.6 \pm 0.20B$
Cl	$<1.0 \pm 0.00A$	$2.6 \pm 0.18B$

^a Control, non-treated water; PAA, peroxyacetic acid (8 mg/liter); Cl, calcium hypochlorite (2 mg/liter free chlorine). ^b Within columns, means followed by same letter are not different ($p < 0.05$).

During the course of the study, the research team also conducted a series of “challenge” experiments using non-pathogenic *E. coli* TVS353 to mimic high biological loading under Objective 2. This evaluation allowed the team to report back to industry on the ability of each of the treatment options to respond to extreme microbial loading events as well as allow the research team to calculate commercial field-scale log reductions. Throughout the challenge experiments, the research team followed the framework outlined by Harris et al. (2012, 2013) and Suslow (2011), using established SOPs and shared protocols for the evaluation of microbial hazards and controls during production that pertain to the quality of agricultural water contacting fresh produce that may be consumed raw.

At the initiation of the challenge experiments, isolates of *E. coli* TVS353 were screened to confirm their identity (e.g., no change in morphology or absence of specific virulence genes). The bacterial strain was provided by the Rock laboratory -80 archives to maintain consistency. Before the target organisms were inoculated into the water source, the microbial population concentration was determined at various stages using an appropriate selective medium specific for the target microorganism(s), e.g., (i) after the initial growth of bacteria in culture medium, (ii) immediately before and after blending with the water carrier (phosphate buffered saline solution), and (iii) after application to the environmental water matrix. Final concentrations of the target organism(s) in the inoculated water aimed to reflect high microbiological loading (approximately 1×10^4 CFU/100mL irrigation water). The research team recognizes that the occurrence of bacteria in agricultural water at this concentration may be rare, however, felt it necessary to fully evaluate the log reduction thresholds for each of the antimicrobial treatments.

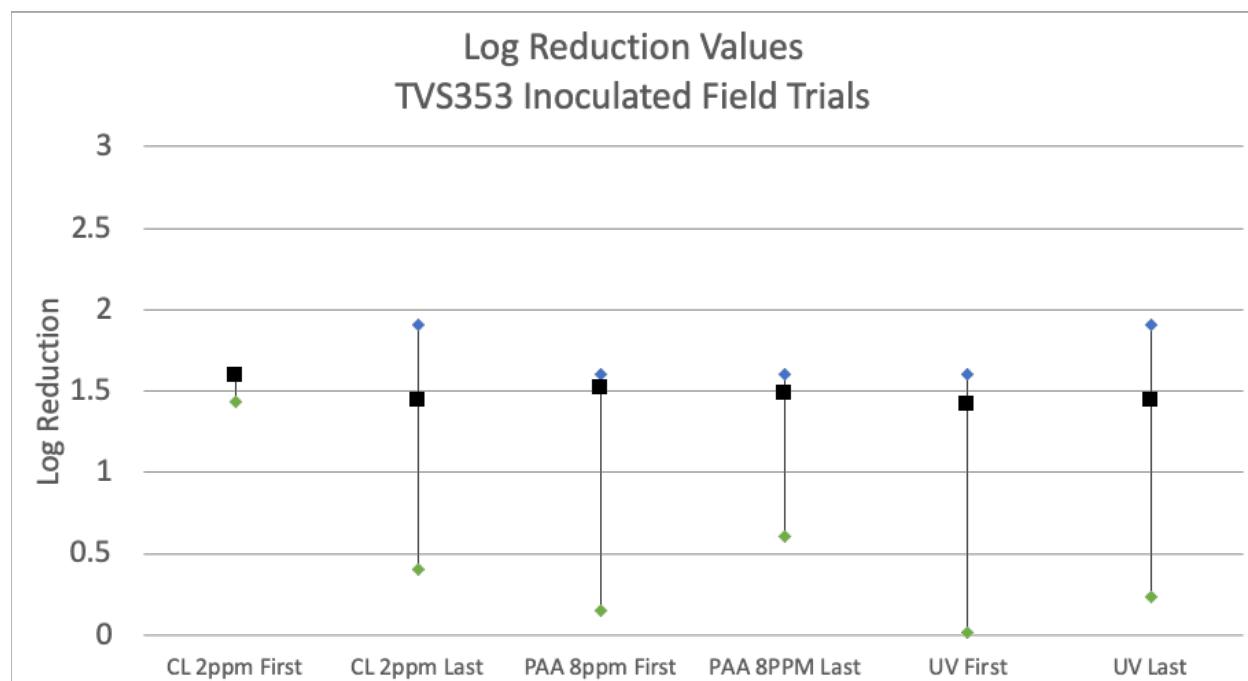
The TVS353 bacterial stock solution was injected into the irrigation main line using a positive displacement pump at a known rate (mL per minute) to achieve the targeted microbial loading in the source water. Water samples were collected in sterile 1-L polypropylene containers in the canal or ditch representing “background” as well as post-treatment at the first and last sprinkler head locations. Samples of the inoculum were also collected the day of each experiment to be used to calculate log reductions. Samples were stored on ice in coolers until processing within 6 hours of collection. Appropriate quenching reagents were used for each sanitizer: Sodium Metabisulfite (SMBS) for PAA and Hydrogen Peroxide (H₂O₂) and Sodium Thiosulphate for Sodium Hypochlorite treatments. Water treatment trials were conducted in triplicate and included both positive (1-acre plots where no sanitizer was used) and negative fields (1-acre plots where no bacteria was applied) for control purposes.

It should also be noted that all sampling events included the proper number of both positive and negative controls to ensure confidence in sample results. In order to calculate log reductions of bacteria from each sanitizer, 100 ul of collected water sample was direct plated in-duplicate on selective media and 100 ml of each water sample was filtered in duplicate onto a 0.45-micron filter (Millipore SAS, 67120 Molsheim, France) and then placed on selective media followed by incubation at 37°C for 18–24 hours before counting. Additional sample dilutions ranging from 0

to 1:1,000 were also plated in duplicate to aid in Log Reduction Value (LRV) determination. Resulting colonies were reported as CFU/100ul or CFU/100ml respectively. Additionally, to increase the sensitivity of the analysis, five cheese cloth filters were placed in the field in a star pattern surrounding the first and last sprinkle head (each) at the start of irrigation. After the irrigation set had been completed, filters were collected and placed into sterile Whirl-pak bags and place on ice until analysis. Once in the laboratory, 90 ml of enrichment broth were added to each bag/filter and hand massaged for 1 minute. All sample enrichments were incubated at 37°C for 18–24 hours. After incubation, approximately 100 ul of sample enrichments were assayed by spread plate technique onto selective media, ChromAgar ECC supplemented with 80mg/L rifampicin (ChromAgar, Paris, France) in duplicate. Samples resulting in blue colonies on selective media were counted as positive for the bacteria of interest (TVS353). Numbers of bacteria from pre- and post-treatment samples were used to calculate LRVs for each treatment strategy evaluated in addition to the non-treatment control.

The following figure (**Figure 31**) depicts average log reductions for PAA, Calcium Hypochlorite, and UV light for inoculation trials conducted in Maricopa. For the inoculated field trials a target of 2 ppm residual of free chlorine as well as 8 ppm of PAA were targeted for evaluation. All log reduction values achieved at or near 1.5-log reduction across all treatments evaluated. While this is noteworthy, it is important to note the deviation in performance of the evaluated chemistries from the benchtop experiments to the field-based experiments is significant. Additionally, the currently EPA/FDA protocol requires a minimum of 3-log reduction for treatment options use in agricultural water in preharvest environments.

Figure 31. Average log reduction vales of TVS353 in inoculated field trials



Additionally, the research team was able to demonstrate the impact of turbidity or suspended particulates on the efficacy of UV light to reduce generic *E. coli* and total coliform bacteria in field evaluations. During subsequent evaluation, the research team worked with field crews to disturb canal sediments to create “worst case” scenarios for water treatment. Turbidities evaluated ranged from 4.3 to 910 NTU.

Figures 32 and 33 below show total coliform bacteria and *E. coli* concentrations at the riser immediately post-treatment with respect to turbidity. As the red trend lines indicates, it is easily seen that as turbidity increases, we also see a reduction in UV effectiveness to reduce naturally occurring bacteria. It may be important to characterize average turbidity or water clarity in ranch locations selected for the use of UV disinfection in order to gauge if the technology would be successful. Additional pre-treatment including filtration to reduce particulates, the use of UV in conjunction with other complementary chemistries such as PAA to form hydroxyl-radicals, as well as enhanced monitoring can all be used to enhance the effectiveness of UV disinfection.

Enhanced monitoring may include measurement of UV transmittance. UV transmittance, also known as ultra violet transmittance or UVT, refers to the percentage of light that passes through a water sample at the wavelength of 254 nm. UVT relates to the organics, colloidal solids, and suspended particles that absorb and scatter this UV light wavelength. UV transmittance measurements provide valuable information related to the amount of natural organic matter (NOM) in the water sample and there are numerous hand-held units available for purchase (Senorex.com). Data characterizing the organic contents of the sample water can be used to control and help optimize UV treatment of agricultural water. Nevertheless, our research team was able to measure average log reduction values ranging from 0.56 to 0.61 during elevated turbidity conditions, thus demonstrating that even in the most challenging water quality conditions, UV light can be an effective agricultural water treatment alternative to other conventional chemistries.

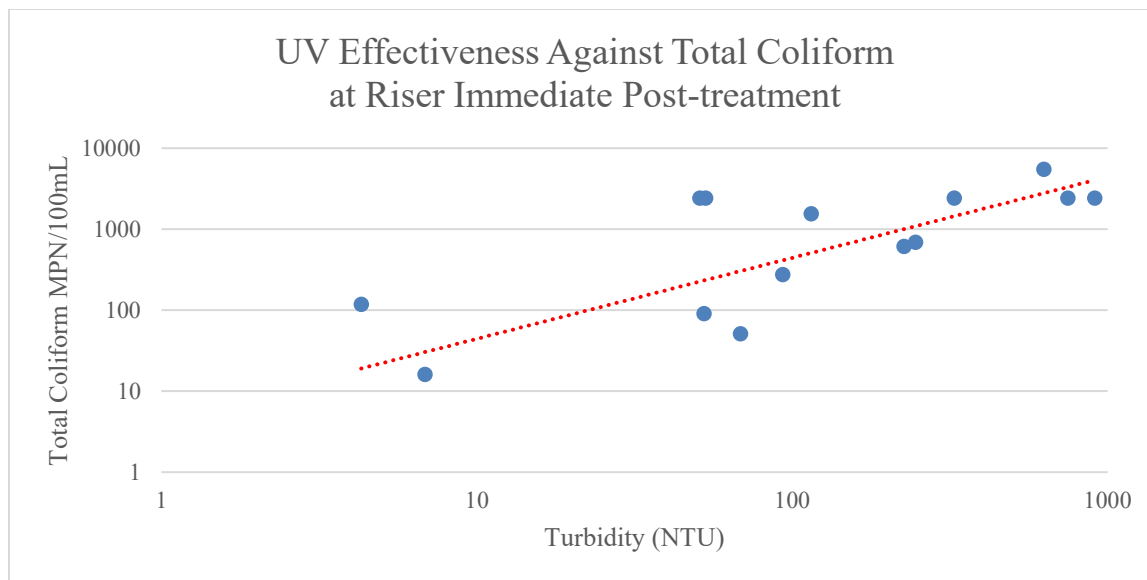


Figure 32. UV effectiveness against Total Coliform bacteria at the riser immediately post-treatment. (*Red line denotes linear trend line.)

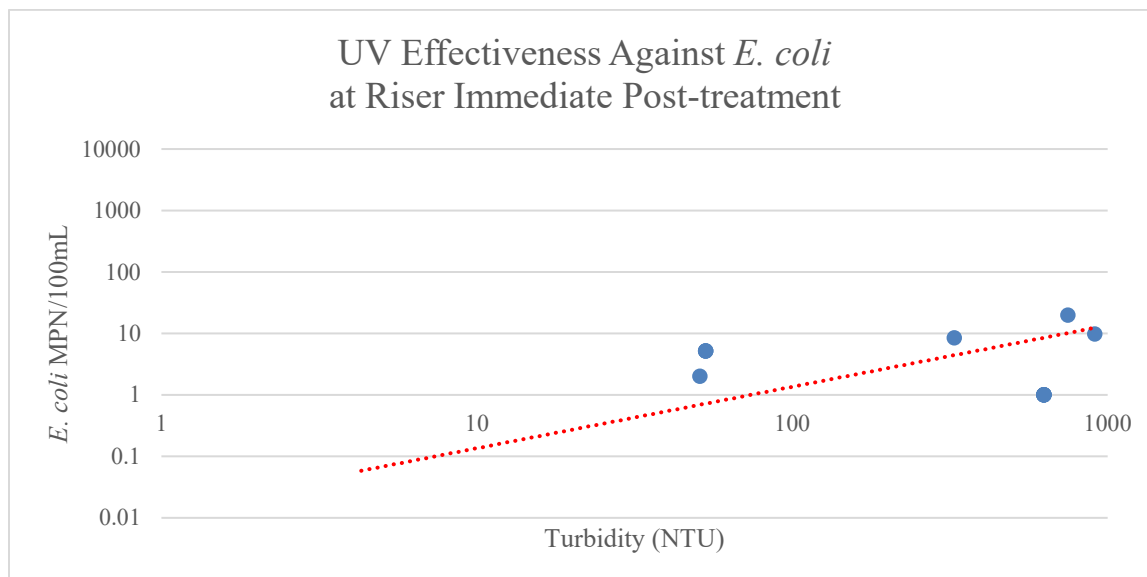


Figure 33. UV effectiveness against *E. coli* at the riser immediately post-treatment. (*Red line denotes linear trend line.)

For non-irrigation water sample collection, the research team employed direct plate count as well as enrichment of either soil or plant tissue, followed by plating on selective media for the detection of the applied *E. coli* TVS353. Raw-product preharvest samples represented by 5 heads of romaine as well as soil samples (~225 grams) were collected from five locations surrounding the first and last sprinkler heads (each) for evaluation of residual bacteria that may have survived post treatment.

Figure 34. Sample collection types for inoculated field trials



Results from raw-product romaine lettuce samples collected 7 days after irrigation in each of the treatment plots indicated detectable levels (40%; 20%) of *E. coli* TVS353 in plots treated with PAA at the first and last sprinkler heads, while plots treated with Calcium Hypochlorite resulted in non-detectable levels of bacteria (0%) at the first sprinkler head and 40% positive samples at the last sprinkler head. UV treatments resulted in 60% and 100% positive detections on raw-product romaine lettuce samples collected post-treatment. Similar results were seen when evaluating soil samples collected in five zones per treatment plot post-treatment. Plots treated with PAA and Calcium Hypochlorite resulted in 0% positive detections in soil at both the first and last sprinkler head locations versus 100% positive detections in soil collected from UV treatment plots at both sprinkler head locations. Results from enriched cheese-cloth filters indicates nearly 100% positivity for all treatments and sample collection locations (**Table 5**). These results indicate that while water samples may indicate little to no bacteria was detected in the water sample in 100mL volumes post-treatment, residual and surviving bacteria are able to be detected in both raw-product and soil samples post-treatment across all chemistries evaluated.

Table 5. Results of soil, romaine, and enriched filter samples post-treatment

Treatment/Location	Soil	Romaine	Filter
CL 2ppm/First	0%	0%	100%
CL 2ppm/Last	0%	40%	100%
PAA 8ppm/First	0%	40%	80%
PAA 8PPM/Last	0%	20%	100%
UV/First	100%	60%	80%
UV/Last	100%	100%	100%
No Treatment Control/First	100%	100%	100%
No Treatment Control/Last	100%	100%	100%

Objective 4: Microbiome analysis. This section of the report describes the impact of treating agricultural water with disinfectants/sanitizers on the microbiome of the phyllosphere (plant tissue), rhizosphere (roots) 7 days post-treatment and in soil from 7 days to an additional 3 months (90 days) after treatment.

Sample collection and processing. Across the duration of the project, microbiome samples (phyllosphere, rhizosphere, and soil) were collected from five different field locations, including two study fields in Arizona (Yuma and Maricopa), two study fields in Texas (Edinburg and Uvalde), and one commercial field in Arizona. The microbiomes of either spinach, romaine lettuce, or mint fields were examined for the impact of sanitizer treatment of agricultural water for irrigation during the study. During collection, phyllosphere (plant tissue) samples were a composite of five (5) leaf grabs pooled together, while soil and rhizosphere samples were individual samples. Samples were collected prior to agricultural water treatment with the sanitizers and then 7 days after the application of treated water. Additional soil samples were also collected 3 months after initial water treatment to determine any long-term microbiome impacts at the two Arizona study field locations (it was not possible at other locations due to field turnover). Soil samples included two samples, one that was 1–2 inches deep (topsoil) and another 4–5 inches deep (bottom soil) from each of the sampled locations (first and last sprinkler head) for each treatment. To date, only the topsoil has been analyzed for the study, as it was most exposed to the treated water. In total, there were 622 samples collected for the study, as indicated in **Table 6**. Collected samples were divided into two parts. One part was treated with propidium monoazide (PMA) prior to DNA extraction, which allows for detection of predominately living bacterial cells and eliminates most dead bacterial cells to provide an accurate assessment of the living bacterial communities of the sample. The other part was not treated with PMA and thus detected both living and dead bacterial DNA for an assessment of overall bacterial community of each sample.

Table 6. Microbiome sample collection by location

Location	Plant Leaves	Rhizosphere	Soil	Total
Yuma, AZ	36	36	96	168
Maricopa, AZ	48	48	72	168
Edinburg, TX	36	36	48	120
Uvalde, TX	36	36	48	120
Commercial	15	15	16	46
Total	171	171	280	622

Yuma, AZ microbiome. All of the p-values from the permanova comparisons of the bacterial diversity of spinach, spinach rhizosphere, and soil by the various agricultural water treatments are listed in **Table 7**. The bacterial diversity of the spinach phyllosphere was significantly altered due to the administration of PAA to the agricultural water after 7 days from the initial treated water usage, which included altering the PMA-treated (living) (p-value = 0.003), total DNA (p-value = 0.002), and overall (combination of PMA-treated and total DNA) bacterial diversity of the phyllosphere (p-value = 0.001). Chlorine-treated water did not have similar impact on the diversity as PAA for the spinach phyllosphere; there was a statistically significant difference between PAA- and chlorine-treated water on the overall microbiome diversity (p-value = 0.009).

Table 7. P-values for spinach bacterial diversity based on treatment for Yuma, AZ*

	Control vs PAA	Control vs Chlorine	PAA vs Chlorine
Spinach			
PMA (living communities)	0.003	0.355	0.241
Total DNA	0.002	0.206	0.033
Overall	0.001	0.046	0.009
Spinach Rhizosphere			
PMA (living communities)	0.002	0.001	0.065
Total DNA	0.026	0.011	0.357
Overall	0.002	0.003	0.385
Spinach Soil			
PMA (living communities)	0.029	0.143	0.413
Total DNA	0.277	0.387	0.144
Overall	0.025	0.020	0.016

*NOTE: p-value ≤ 0.01 was considered significant

The heatmap of the spinach phyllosphere microbiome (**Figure 35**) demonstrates the major differences between the control spinach and the spinach phyllosphere exposed to PAA-treated water; in addition, although not statistically significant, it demonstrates that chlorine-treated water also resulted in microbiome shifts. Additionally, examination of the taxonomic relative abundance of the spinach phyllosphere demonstrates that many different bacterial families were altered due to the use of both PAA- and chlorine-treated water (**Figure 36**). Several of the top bacterial families that were more prevalent in PAA- or chlorine-treated water exposed spinach phyllosphere included Pseudomonadaceae, Rhodospirillaceae, and Xanthomonadaceae, whereas Bacillaceae and Nitrosoarchaeaceae were decreased in the spinach phyllosphere when exposed to PAA- or chlorine-treated water. Both PAA- and chlorine-treated agricultural water exposure resulted in statistically significant changes to the spinach rhizosphere by 7 days. PAA-treated water exposure statistically significantly altered the bacterial diversity of the PMA-treated (living) (p-value = 0.002) and overall (combination of PMA-treated and total DNA) microbiome (p-value = 0.002) of the spinach rhizosphere, while chlorine-treated water exposure also resulted in statistically significant changes to the bacterial diversity of the PMA-treated (living) (p-value = 0.001) and overall (combination of PMA-treated and total DNA) microbiome (p-value = 0.003) of the spinach rhizosphere. Unlike the spinach phyllosphere there was no statistically significant difference between PAA- or chlorine-treated water exposure to the microbiome shifts of the spinach rhizosphere for either the PMA-treated (living) (p-value = 0.065), total DNA (p-value = 0.357) or overall (combination of PMA-treated and total DNA) microbiome (p-value = 0.385). Again, the heatmap of the different microbiome spinach rhizosphere samples demonstrates these changes in the microbiome composition with the exposure to different types of water treatment compared to the control group (**Figure 37**). Interestingly, the shift in bacterial abundance of the spinach rhizosphere did not have the same dramatic loss or gain of different bacterial families as was present in the spinach phyllosphere; instead, it was more changes in the overall abundance of the different bacterial families present in the rhizosphere like Pseudomonadaceae, Gemmatimonadetes, and Oxalobacteraceae, to name a few (**Figure 38**). None of the topsoil microbiome samples were affected by either treatment of the agricultural water either at 7- or 90-days post-treatment during the study, which can be demonstrated by the topsoil heatmap (**Figure 39**) and the taxonomic relative abundance for the topsoil (**Figure 40**). Throughout the study none of the topsoil microbiomes for any leafy green commodity or location were statistically significantly altered by any of the agricultural water treatments.



Figure 35. Overall spinach microbiome of different samples from fields in Yuma, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker green the square the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) that are present in the sample.

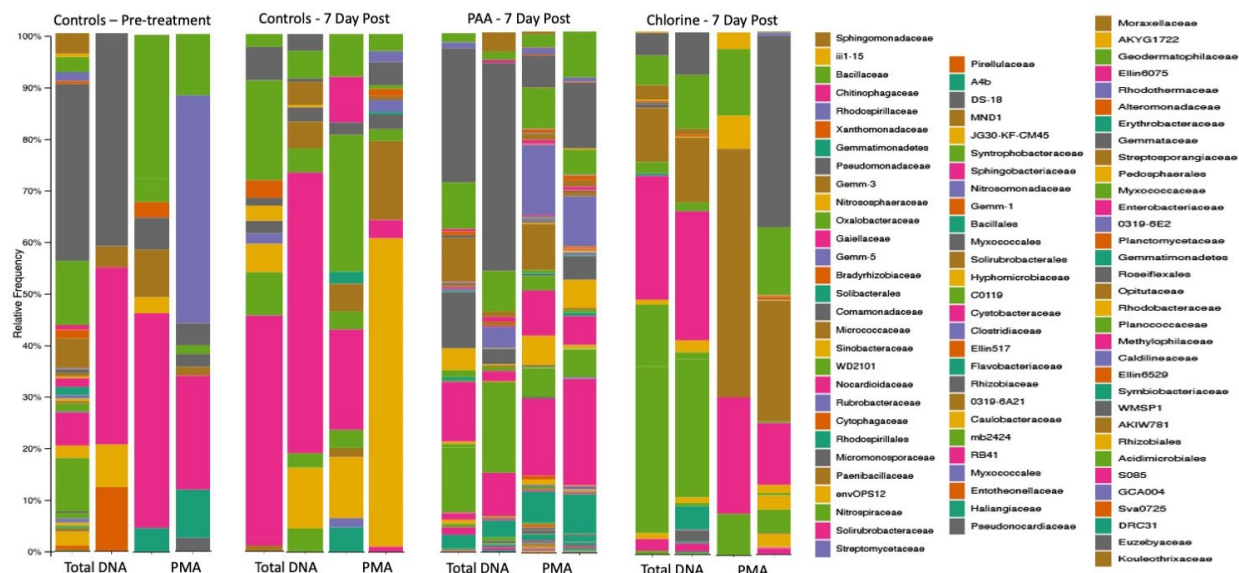


Figure 36. Consensus relative frequency of specific bacterial families in different spinach samples from Yuma, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Demonstrates major shifts in specific bacterial families due to treatment of agricultural water with different disinfectants/sanitizers.

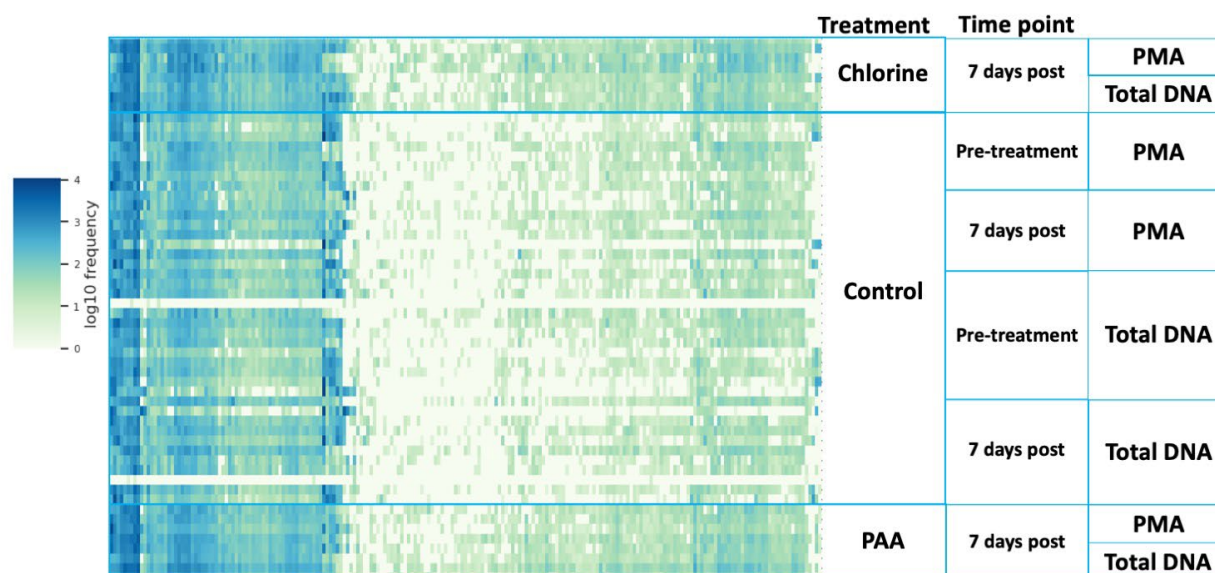


Figure 37. Overall spinach rhizosphere microbiome of different samples from fields in Yuma, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker blue the square, the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) that are present in the sample.

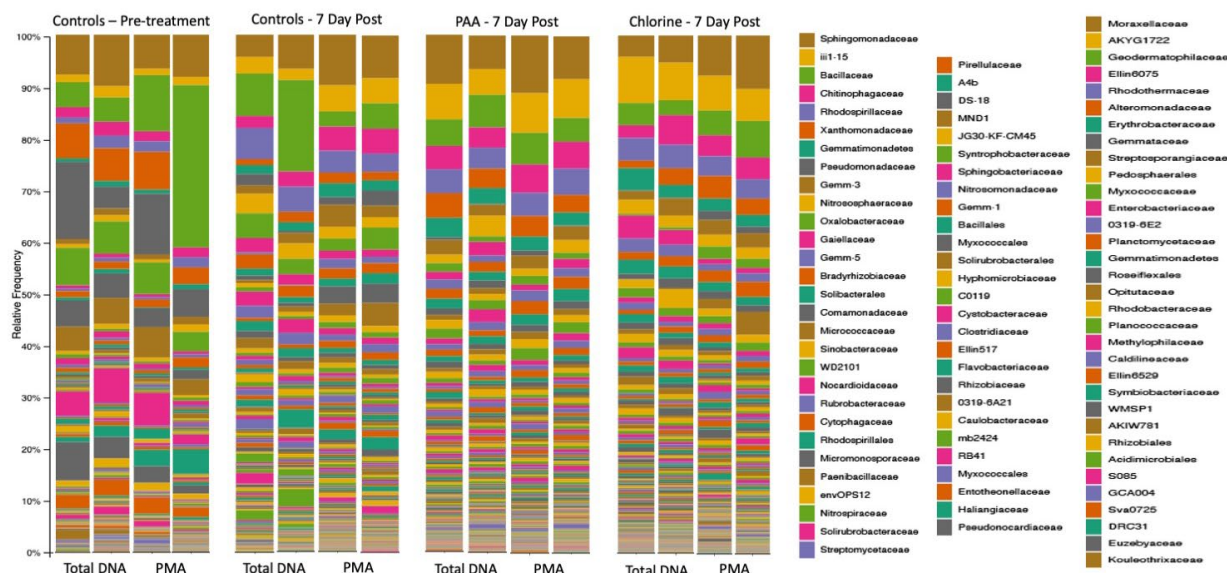


Figure 38. Consensus relative frequency of specific bacterial families in different spinach rhizosphere samples from Yuma, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Demonstrates major shifts in specific bacterial families due to treatment of agricultural water with different disinfectants/sanitizers.

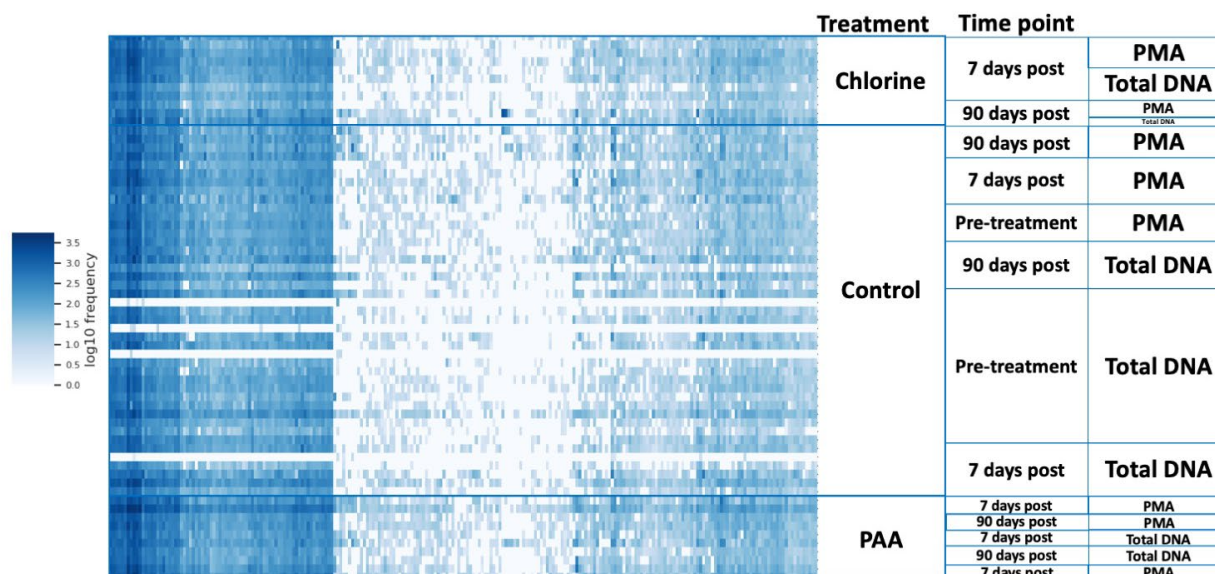


Figure 39. Overall spinach topsoil microbiome of different samples from fields in Yuma, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker blue the square the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) that are present in the sample.

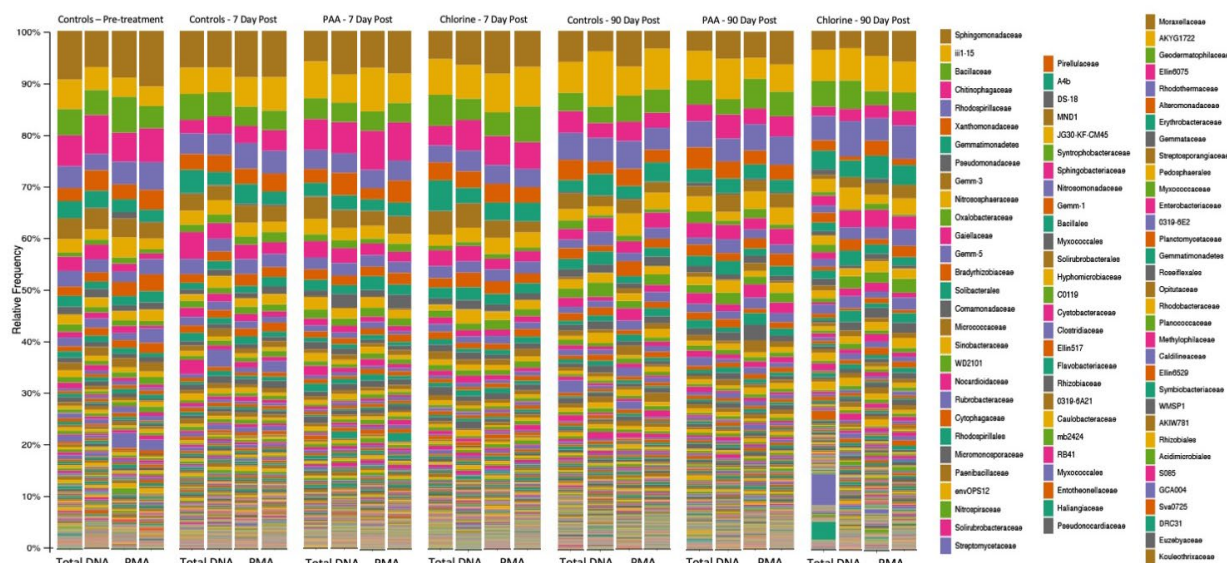


Figure 40. Consensus relative frequency of specific bacterial families in different spinach topsoil samples from Yuma, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Demonstrates major shifts in specific bacterial families due to treatment of agricultural water with different disinfectants/sanitizers.

Maricopa, AZ microbiome. All of the p-values from the permanova comparisons of the bacterial diversity of romaine lettuce, romaine lettuce rhizosphere, and soil by the various agricultural water treatments are listed in **Table 8**. However, the only statistically significant impact was by chlorine treatment on the living bacteria (PMA-treated) of the romaine lettuce leaves (p-value = 0.003). Although there were still overall shifts in the romaine lettuce microbiome between the different treatments compared to the pre-treatment microbiome of the romaine lettuce for both PAA and chlorine treatment, it is most evident in the chlorine-treated samples (**Figure 41**). Whereas the rhizosphere of the romaine lettuce did not appear to have any major shifts in the microbiome, no matter which of the treatments was applied to the agricultural water for irrigation (**Figure 42**). None of the topsoil microbiome samples were affected by either treatment of the agricultural water, either at 7- or 90-days post-treatment during the study. This finding suggested that treating the agricultural water with either PAA or chlorine did not have a major impact, particularly long-term on the microbiome of romaine lettuce, romaine lettuce rhizosphere or topsoil in the fields in Maricopa, AZ during the study.

Table 8. P-values for romaine bacterial diversity based on treatment for Maricopa, AZ*

	Pre-treatment vs PAA	Pre-treatment vs Chlorine	Pre-treatment vs Both
Romaine			
PMA (living communities)	0.105	0.003	0.674
Total DNA	0.528	0.115	0.141
Overall	0.192	0.031	0.105
Romaine Rhizosphere			
PMA (living communities)	0.528	0.957	0.599
Total DNA	0.293	0.141	0.674
Overall	0.141	0.316	0.497
Romaine Soil			
PMA (living communities)	0.386	0.386	0.772
Total DNA	0.563	0.288	0.386
Overall	0.462	0.643	0.400

*NOTE: p-value ≤ 0.01 was considered significant



Figure 41. Overall romaine lettuce microbiome of different samples from fields in Maricopa, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker green the square the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) that are present in the sample.

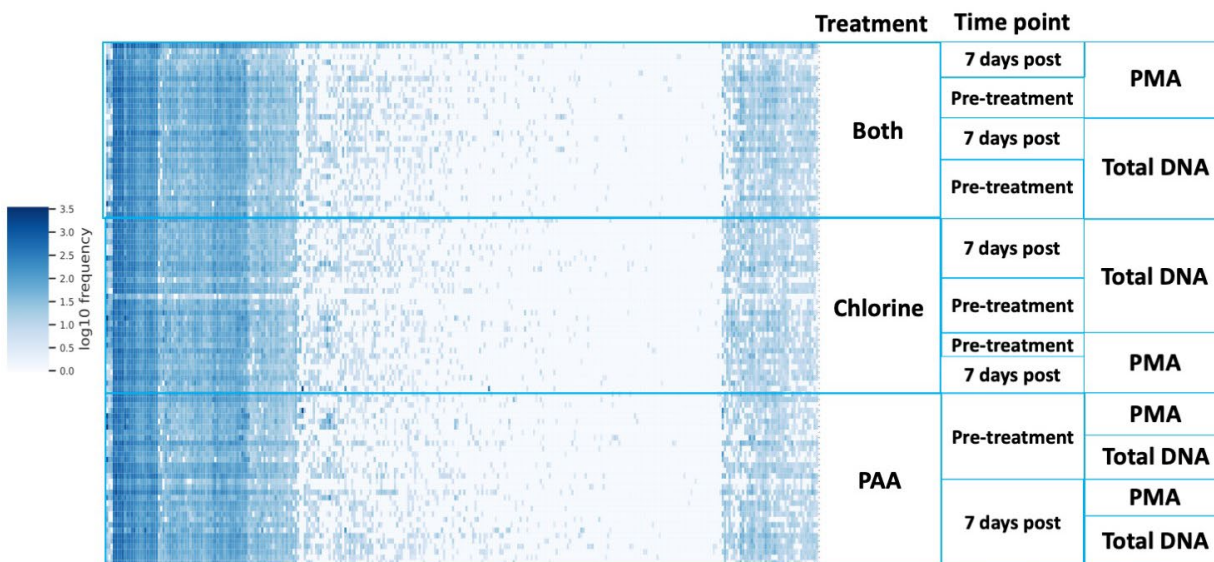


Figure 42. Overall romaine lettuce rhizosphere microbiome of different samples from fields in Maricopa, AZ at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker blue the square the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) present in the sample.

Edinburg, TX microbiome. All of the p-values from the permanova comparisons of the bacterial diversity of mint, mint rhizosphere, and soil by the various agricultural water treatments are listed in **Table 9**. Neither of the treatments (PAA or chlorine) to the agricultural water resulted in a statistically significant change to the mint microbiome during the study. While there were some shifts or changes due to the water treatments, there were not any major changes/shifts in the mint microbiome (**Figure 43**). However, PAA treatment of the agricultural water did have a statistically significant impact on the bacterial diversity of the mint rhizosphere for the PMA-treated (living) (p-value = 0.009), total DNA (p-value = 0.004) and overall (combination of PMA-treated and total DNA) microbiome (p-value = 0.00009), whereas chlorine treatment of the water also resulted in a statistically significant change for the overall (combination of PMA-treated and total DNA) microbiome of the mint rhizosphere (p-value = 0.0009). Both of these changes caused by the different treatments can be clearly observed in the heatmap (**Figure 44**). None of the topsoil microbiome samples were affected by either treatment of the agricultural water either at 7- or 90-days post-treatment during the study.

Table 9. P-values for mint bacterial diversity based on treatment for Edinburg, TX*

	Control vs PAA	Control vs Chlorine	PAA vs Chlorine
Mint			
PMA (living communities)	0.741	0.204	0.212
Total DNA	0.563	0.073	0.179
Overall	0.538	0.107	0.262
Mint Rhizosphere			
PMA (living communities)	0.009	0.243	0.908
Total DNA	0.004	0.013	0.862
Overall	0.00009	0.0009	0.804
Mint Soil			
PMA (living communities)	ND	ND	ND
Total DNA	ND	ND	ND
Overall	0.205	0.235	0.909

*NOTE: p-value ≤ 0.01 was considered significant



Figure 43. Overall mint microbiome of different samples from fields in Edinburg, TX at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker green the square the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) that are present in the sample.

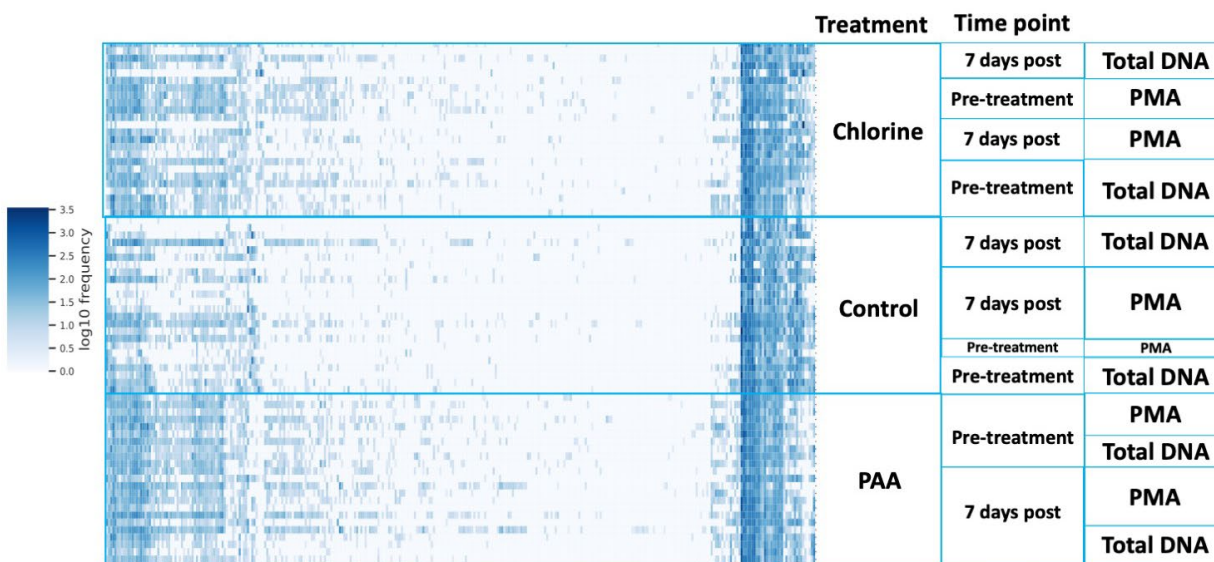


Figure 44. Overall mint rhizosphere microbiome of different samples from fields in Edinburg, TX at different time points (pre-treatment vs 7 days after water treatment) including different treatments of agricultural water. Additionally, includes bacterial community differences between PMA treated (living bacterial communities only) or total DNA (DNA of all bacteria present in the sample, living and dead) of different samples. The darker blue the square the more that particular bacteria were present in the sample. Samples read from right to left for definition of the sample and the bacterial communities (microbiome) that are present in the sample.

Uvalde, TX microbiome. Delays due to the COVID-19 pandemic along with other issues experienced by the co-PI resulted in major problems with these samples. These samples did not arrive in top quality for microbiome analysis; although the samples were processed and sequenced, it was decided best not to include the analysis in the overall report as it might be heavily biased by the poor quality of the samples after shipping.

Commercial field microbiome. Delays due to the COVID-19 pandemic limited the ability to analyze these samples after sequencing, but we are currently in the process of getting them analyzed and will be included in any publications or future reports.

Outcomes and Accomplishments

- Over the course of the study, the research team has conducted 1-acre field trials of spinach, romaine, and mint in Yuma and Maricopa, AZ, as well as Edinburg and Uvalde, TX, on the following sanitizers/devices: 1) PAA, 2) Calcium Hypochlorite, 3) Chlorine Dioxide, 4) UV light, and 5) raw water control.
- In addition to controlled field trials, the team also completed replicate in-field evaluations on grower collaborator fields in both Yuma and Maricopa, AZ.
- As stated previously, concurrently with field trials, the research team evaluated the accuracy of three commercially available and emerging test strips/kits for quantifying the effectiveness of antimicrobial water treatments as well as a range of physical and chemical parameters.
- Both the RQflex®20 reflectometer and the Quantofix® Relax field meters have been evaluated for PAA analysis. While the RQ Flex works well in controlled laboratory conditions, it has repeatedly shown to be problematic in field conditions. Similarly, we saw complementary results when evaluating the HACH DR300 Pocket Colorimeter for free chlorine as well as titration for chlorine dioxide. While the meters provide more accurate readings, we have found that test strips offer a cost-effective alternative that are easy to use for industry.
- Data across all treatments and locations indicates that residual chemical is detected fairly quickly at the first sprinkler head after system stabilization (full pressure) within 5 minutes. However, for all sanitizers evaluated, time from system startup to residual disinfectant detection at the last sprinkler head ranged from 25 to 35 minutes after system stabilization (less than 5-acre plot).

- This result was amplified in larger commercial field plots, with system “stabilization” taking well over one hour for fully treated water to reach the last sprinkler in plots of 10 to 35 acres. This more accurately mimics grower field conditions and ranch sizes and should be noted.
- All sanitizers evaluated were able to easily achieve 2-log reduction in naturally occurring total coliform bacteria at the first sprinkler head with similar results at the last sprinkler head once residual was detected. However, in all treatments evaluated, there was bacterial breakthrough after systems had been stabilized, indicating that treatment can be variable.
- Similar results were also seen for the UV unit evaluated, ranging between 0.6 to 2.1 log reduction at both the first and last sprinkler head when compared to concentrations of total coliform bacteria and generic *E. coli* in the source water.
- Overall, the microbiome portion of the project found that PAA had the strongest impact or effect on the bacterial diversity of different commodities no matter the location or growing region. However, both chlorine- or PAA-treated agricultural water can have a statistically significant impact on the bacterial diversity of phyllosphere or rhizosphere of different leafy greens for at least 7 days after administration of treated water.
- There does not seem to be any major microbial shifts in the topsoil at 7- or 90-days post-treatment, which would suggest that there limited long-term impacts of the soil microbiome.
- Nevertheless, additional studies examining the impact on the soil microbiome through multiple seasons is needed to determine if a build-up of salts or other chemicals from the treated agricultural water could result in a shift of the bacterial diversity over the long term.

Future analysis. Additional analysis on the microbiome samples still needs to be conducted, particularly based on conversations with numerous representatives of the leafy greens industry after the recent agricultural water symposium. There were many requests to investigate the general change of the microbiome functionality due to the use of the sanitizers/devices in the agricultural waters. Furthermore, there were requests to explore the role of the microbiome shifts altered due to treated water, particularly in the rhizosphere, on plant and soil health. Finally, analysis on the microbiome shifts in the commercial field due to the treatment of irrigation water needs to be completed (as mentioned above) to understand any differences between commercial production and academic study field sites. All these analyses will be conducted in the near future and included in any publications, additionally an amendment to this report can be generated to make all results easily available to industry representatives.

Summary of Findings and Recommendations

- Data indicate that agricultural water treatment systems are highly dynamic. It is important to note that system “stabilization” is highly variable beyond pressurization of the distribution system, and that sanitizers/devices do not kill microbes instantaneously. These are two key considerations for industry.
- In the bench-top log reduction evaluations, 32°C resulted in greater log reductions than 12°C. This may be important for specific growing regions and/or times of year when industry can expect more or less variability in their agricultural water treatment success.
- Breakthrough of microbial targets was detected on **all sanitizers/devices** evaluated at the first and last sprinkler heads during treatment over time in 1-acre research plots. This is an important finding as we assess how agricultural water treatment systems are regulated and monitored.
- The impact of sample volume increasingly has become important over the course of recent agriculture water treatment studies, including this study. While non-detect for total coliform bacteria or generic *E. coli* in 100ml is the goal, this does not necessarily indicate a non-detect in larger water volumes, on product, or in soil. A true quantitative microbial risk assessment is needed to better determine the detection limits and equivalent sample volume required to assess the risk of contaminating produce with irrigation water and risk to consumers by eating that product.
- It should be noted that microbiome differences were detected on plant tissue and root zone for PAA and chlorine. This was not seen in top soils evaluated by the same methodologies. PAA treatment results in a more significant impact on microbiome than chlorine, indicating a potential prolonged effect or susceptibility of bacterial populations in the microbiome to residual PAA.
- It is important that growers assess when source water conditions may vary and result in significant impact to risk reduction (treatment). Of particular concern are increased turbidity, rainfall, run-off, canal maintenance activities, or any activity that may disturb sediments in the canal upstream.
- It is evident that all chemistries/devices can be successful if implemented properly, however it is important to note that none of the treatments evaluated were effective 100% of the time. Therefore, it is recommended that agricultural water treatment should be viewed as a risk reduction practice rather than a risk elimination practice and should be part of an overall layer approach to food safety.

APPENDICES

Publications and Presentations

CPS Ag Water Treatment – Southwest, Board Meeting and Site Visit, January 30th, 2020

CPS Ag Water Treatment – Southwest, Center for Produce Safety Annual Meeting, July 21st, 2020

Lesson Learned in Agricultural Water Treatment, Desert Ag Conference, June 23rd, 2121

CPS Ag Water Treatment – Southwest, Center for Produce Safety Annual Meeting, July 13th, 2021

CPS Ag Water Treatment – Southwest, Center for Produce Safety Deeper Dive Sponsored Meeting, August 11th, 2021

Budget Summary

Total request: \$202,055.00

Salaries: \$109,588.00

Operations: \$82,245.00

Travel: \$1,455.00

Indirect Costs: \$8,767.00

Suggestions to CPS

Due to the pandemic, the research team could have benefitted from additional time for analysis, however, the project team understands the need for timely data and reporting for industry.

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