There's a Photon in my Water! The Application of Ultraviolet Light Technology to Enhance the Safety of Agricultural Water on Kansas Fresh Produce Farms

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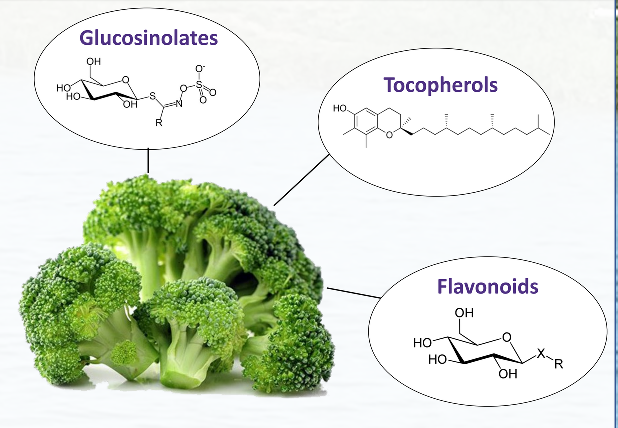
Introduction

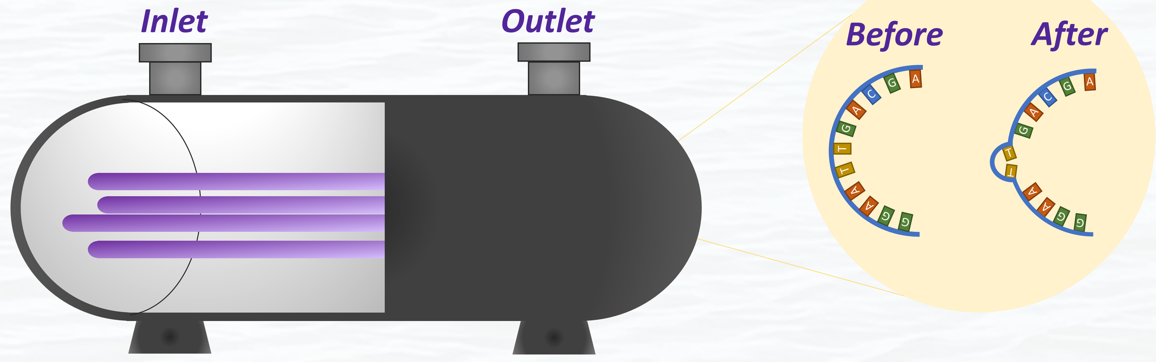
Fresh produce are an excellent source of vitamins, minerals, and health-promoting phytochemicals (example shown to the right).



Unfortunately, fresh produce is also one of the most common vehicles for ***foodborne pathogens***. Many foodborne outbreaks linked to fresh produce were eventually traced back to ***contaminated agricultural water***.

A diagram depicting the flow of a foodborne pathogen throughout the supply chain. As many pathogens persist in agricultural water, irrigation or such water activities transfer the pathogen from the water source to the surface of affected produce. The pathogen continues to replicate during storage, transport, and retail, causing illness in persons who have consumed the affected product raw.

Ultraviolet (UV) light is a physical decontamination method widely used to inactivate human pathogens in drinking water but has yet to be popularized for agricultural water treatment or marketed to growers for such purposes.



An example of a UV-assisted water decontamination system. Water with a high microbial load enters the system through the inlet. Ultraviolet (UV) light induces the formation of T/C dimers which halt DNA replication, and water containing inactivated microorganisms exits the system through the outlet.

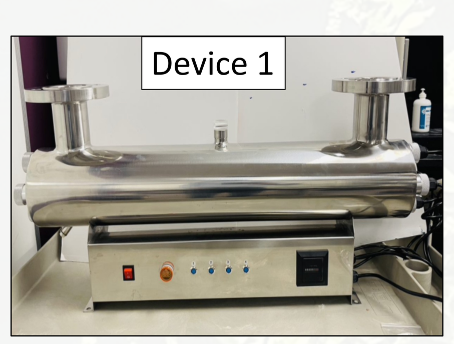
There are ***three main challenges*** for UV-assisted water decontamination systems to treating agricultural water sources:

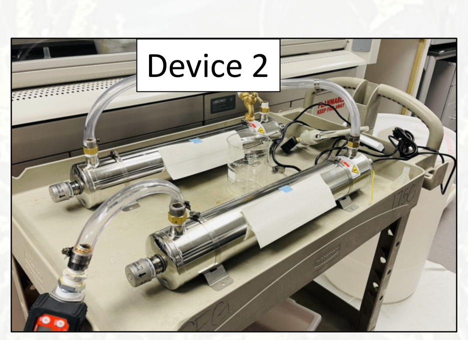
1. ***Particulate matter*** which 'shields' target microorganisms
2. ***Particulate matter*** which absorbs UV light
3. High ***water flow rates*** which decrease treatment efficacy
4. Differential system ***initial and ongoing costs***

Objective

Determine the microbial reduction efficacy and cost-effectiveness of two commercially available UV-assisted water decontamination systems for agricultural water treatment

Specification	Device 1	Device 2
Manufacturer	SARIN Energy Solutions	Atlantic Ultraviolet Co.
Model	UV-25T80	Minipure MIN-9
Flow Rate	1 – 130 GPM (3.8 – 492 LPM)	1 – 9 GPM (3.8 – 34 LPM)
Power	320 W	34 W
UV Lamp No.	4	1
Shell Size (l x w x h)	906mm x 159mm x 360mm	750mm x 108mm x 146mm
Body Material	Stainless Steel	Stainless Steel

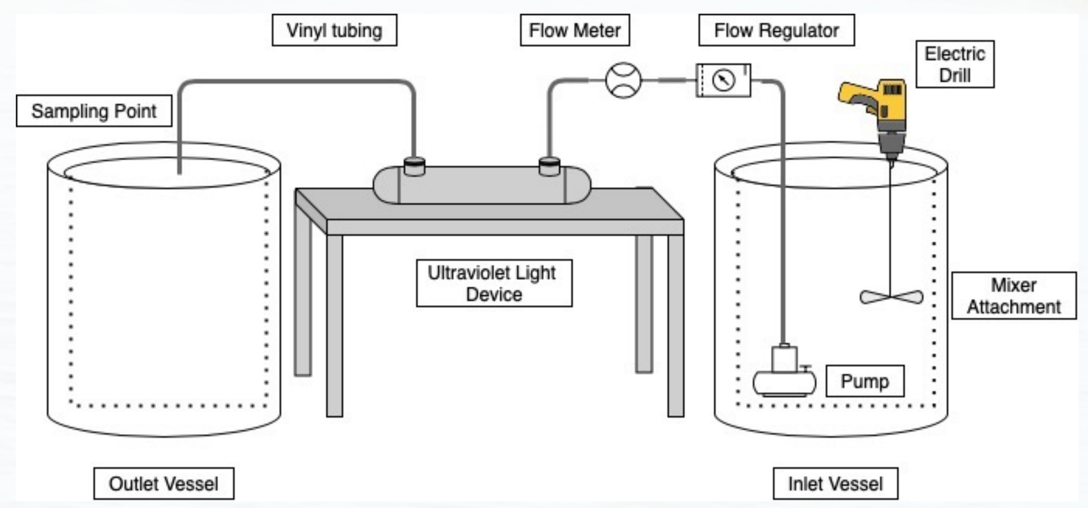




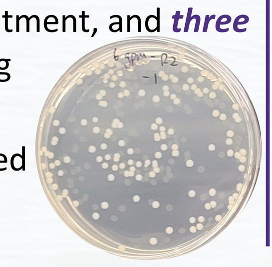
Materials & Methods

In-Lab Validation

1. Device 2 was tested in the laboratory using a water displacement system simulating an on-farm irrigation system

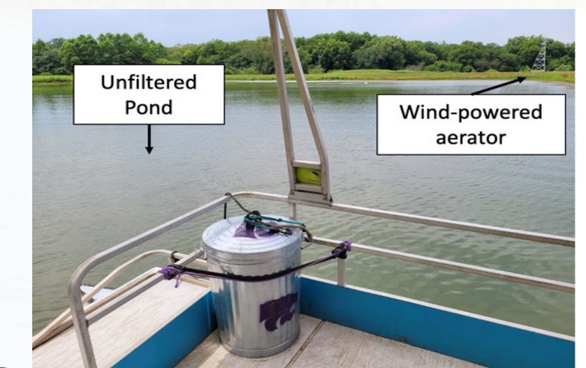


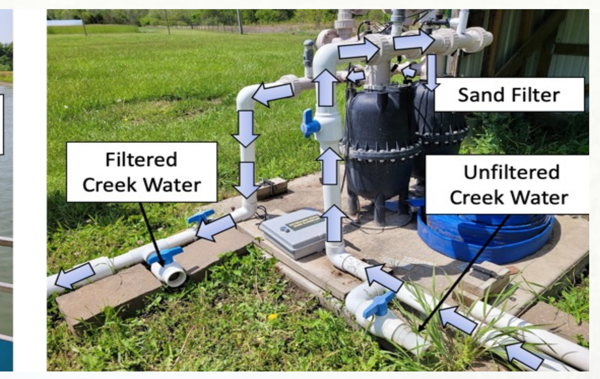
2. The inlet vessel was filled with ***20-gallons of laboratory water***, and %UVT adjusted to ***20%***, ***30%***, or ***40%*** using humic acid
3. ***E. coli*** (ATCC# 25922), ***Salmonella* Typhimurium** (ATCC# 14028) or ***Listeria innocua*** (ATCC# 33090) was added directly to the vessel to achieve an inoculum ***starting concentration of at least 5-log***.
4. Three controls were sampled from the vessel before treatment, and ***three samples were taken at the sampling point*** after reaching flow rates of ***6***, ***7***, and ***9 GPM*** (22.7, 26.5, 34.1 LPM)
5. The ***microbial population*** of each sample was enumerated using Tryptic Soy Agar (TSA).



In-field Validation

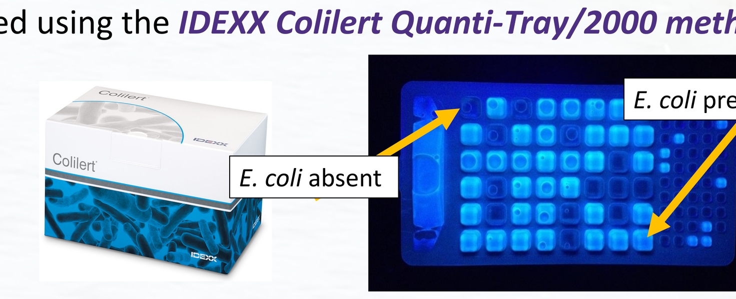
1. The devices were installed in-line with the irrigation system of ***three on-farm water sources***: an unfiltered creek, filtered creek, and an unfiltered pond.





2. The population of ***generic E. coli*** before and after treatment at different flow rates were enumerated using the ***IDEXX Colilert Quanti-Tray/2000 method***

GPM	LPM
6	22.7
7	26.5
9	34.1



3. The ***physiochemical characteristics*** of each water source were determined on each sampling day

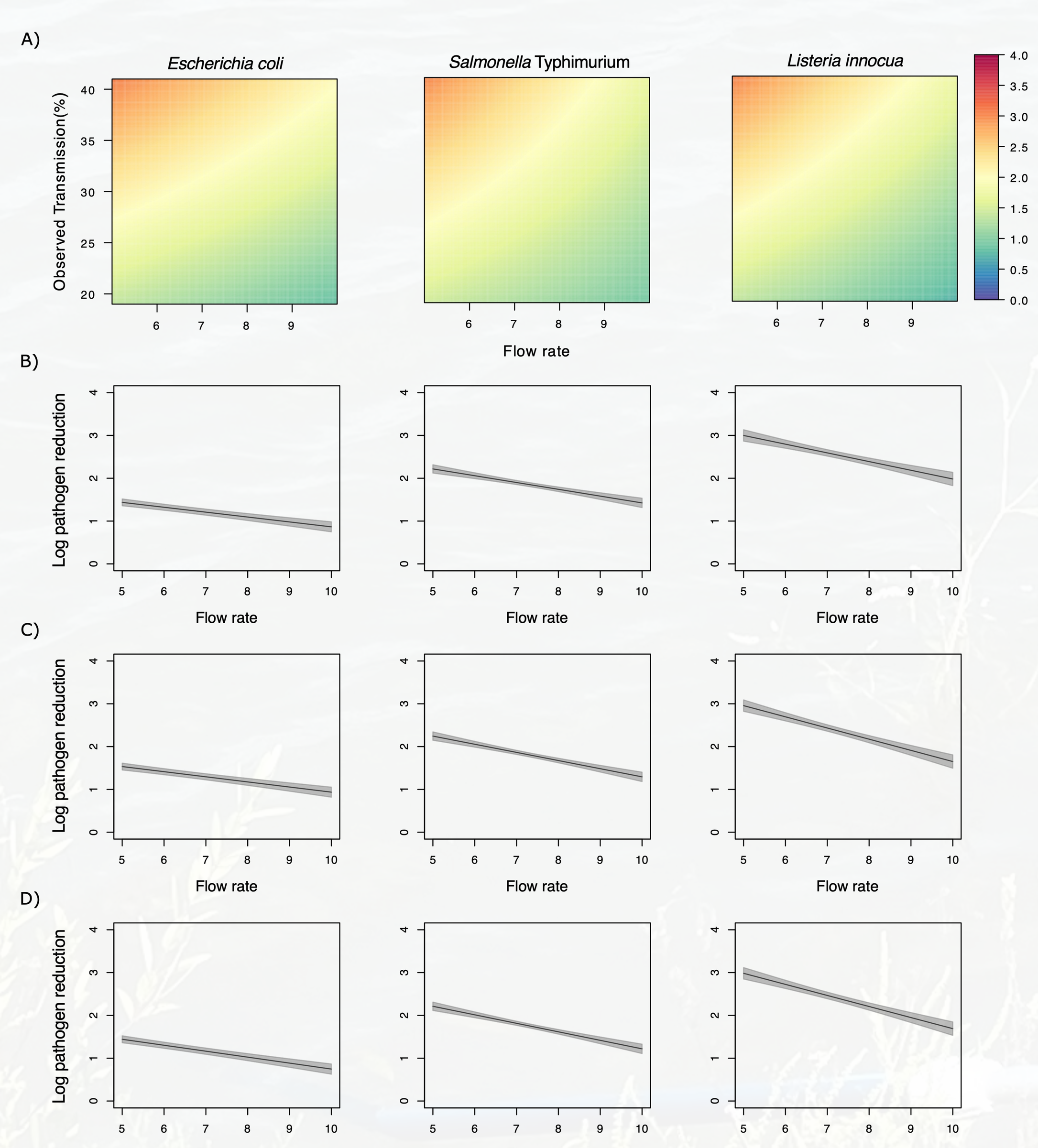
Parameters
UV_{254} Absorbance
$\%UV_{254}$ Transmission
pH
Electrical Conductance
Turbidity

Economic Analysis

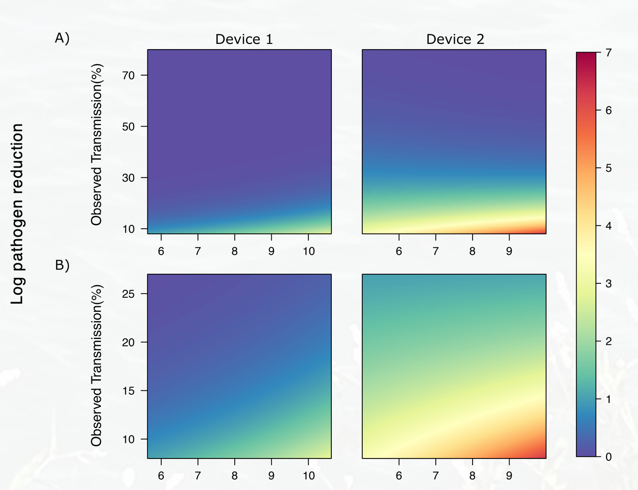
An economic analysis was performed to determine the ***initial and ongoing costs*** of each UV-assisted water decontamination system, accounting for inflation, over a 30-year period

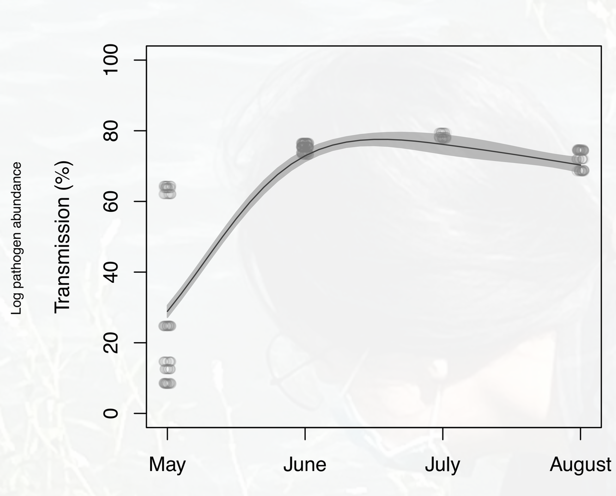
Installation Costs	Operation Costs	Maintenance Costs
Equipment & Fittings	Electricity (kWh)	Replacement Lamps
Operator Training		

Results & Discussion



The microbial reduction efficacy of Device 2 under controlled conditions (***Figure 1***) for each test organism depicted as a dynamic heat map (***A***) or in linear format at 20% (***B***), 30% (***C***), or 40% (***D***) $\%UVT_{254}$.





The microbial reduction efficacy of Device 1 and Device 2 under field conditions for generic *E. coli* (***Figure 2, left***) and the variation in %UVT of the three water sources over the growing season (***Figure 3, right***)

Device 1 Run-time (hrs/day)	Installation Costs (USD)	Operation Costs (USD)	Maintenance Costs (USD)	Total Costs (USD)
1	2,891.92	57.71	2,880.00	5,829.63
2	2,891.92	115.42	2,880.00	5,887.34
3	2,891.92	173.12	2,880.00	5,945.04
4	2,891.92	230.83	2,880.00	6,002.75
5	2,891.92	288.54	2,880.00	6,060.46

Device 2 Run-time (hrs/day)	Installation Costs (USD)	Operation Costs (USD)	Maintenance Costs (USD)	Total Costs (USD)
1	889.43	6.13	2,287.50	3,183.06
2	889.43	12.26	2,287.50	3,189.19
3	889.43	18.39	2,287.50	3,195.32
4	889.43	24.53	2,287.50	3,201.46
5	889.43	30.66	2,287.50	3,207.59

The initial and ongoing of Device 1 (***top***) and Device 2 (***bottom***) over a thirty year period with an average run time of 1-5 hours per day for 365 days

Major Findings, Insights & Limitations

Major Findings

1. The in-lab validation results ***provided the basis*** for the use of UV systems to treat agricultural water with low levels of UV-C transmissibility ($\%UVT_{254}$).
2. The microbial reduction efficacy of both devices was ***negatively impacted*** by turbidity, demonstrating the ***'shielding' effect***.
3. Although increasing the water flow rate negatively impacted the microbial reduction efficacy of both devices, this effect was ***negligible at higher*** $\%UVT_{254}$.
4. Device 1 was ***more effective*** than Device 2 when inactivating generic *E. coli* in agricultural water with a lower $\%UVT_{254}$.
5. The difference in microbial inactivation efficacy of the two devices was ***negligible*** in surface waters with a higher $\%UVT_{254}$.
6. The lowest microbial inactivation efficacy was observed at the ***beginning of the season*** due to the water sources' low $\%UVT_{254}$.
7. Device 2 was less effective at lower $\%UVT_{254}$, but needs ***52.9 to 54.6%*** of the total cost to install, maintain, and operate Device 1.

Major Insights and Study Limitations

This study demonstrates the potential on-farm application of commercially available UV devices to lower the microbial risk of ***agricultural surface waters used in small-scale produce-growing operations***.

However, ***more information*** is required to determine the technology's efficacy for $\%UVT_{254}$ ranges between 30% to 60% and at flow rates reflective of larger produce-growing operations.

This study also provides a basis on the cost-effectiveness of different UV-assisted water decontamination systems, but more information is needed regarding ***actual farm water usage rates*** to improve the estimates of lamp life span and device run-time.

Regarding ***extension education opportunities***, growers using UV-assisted water decontamination systems should be aware of events which may affect their sources' %UVT or turbidity (i.e., heavy rain events, agrochemical use, shock treatments).

Future Studies

Grower Web-based ***Economic Decision Tool***

Grower Input	App Output
$\%UVT_{254}$ or turbidity	UV Dose Required
Organic Load	Reactor Type
Microbial Load	Annual Cost
Flow Rate	

The next steps on this project is to construct a ***computer-based web application*** free of charge for growers to estimate the ***efficacy and costs*** of each reactor for their agricultural water source.

This initiative will support ***chemical-free methods*** for water decontamination in agriculture.

Acknowledgements

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