

# Cleaning Up Irrigation Return Water With Bioreactors

Tom Fernandez

Professor

Department of Horticulture

Michigan State University

# Nursery and greenhouse water and agrichemical (pesticides, nutrients, growth regulators) application





Irrigation return water transports nutrients, pesticides, & other agrichemicals from target and non-target application sites



## Nutrients

Recycled water = recycled nutrients

Runoff water = eutrophication

- Phosphate  $> 0.9 \text{ mg L}^{-1}$
- Nitrate  $> 10 \text{ mg L}^{-1}$



High  $\text{NO}_3$  causing excessive duckweed (*Lemna minor*) and algae growth (including HABs)

## Pesticides

Recycled water = possible phytotoxicity

Runoff water

- Regulatory issues
- Environmental degradation



Speckling on Poinsettia caused by fungicide phytotoxicity

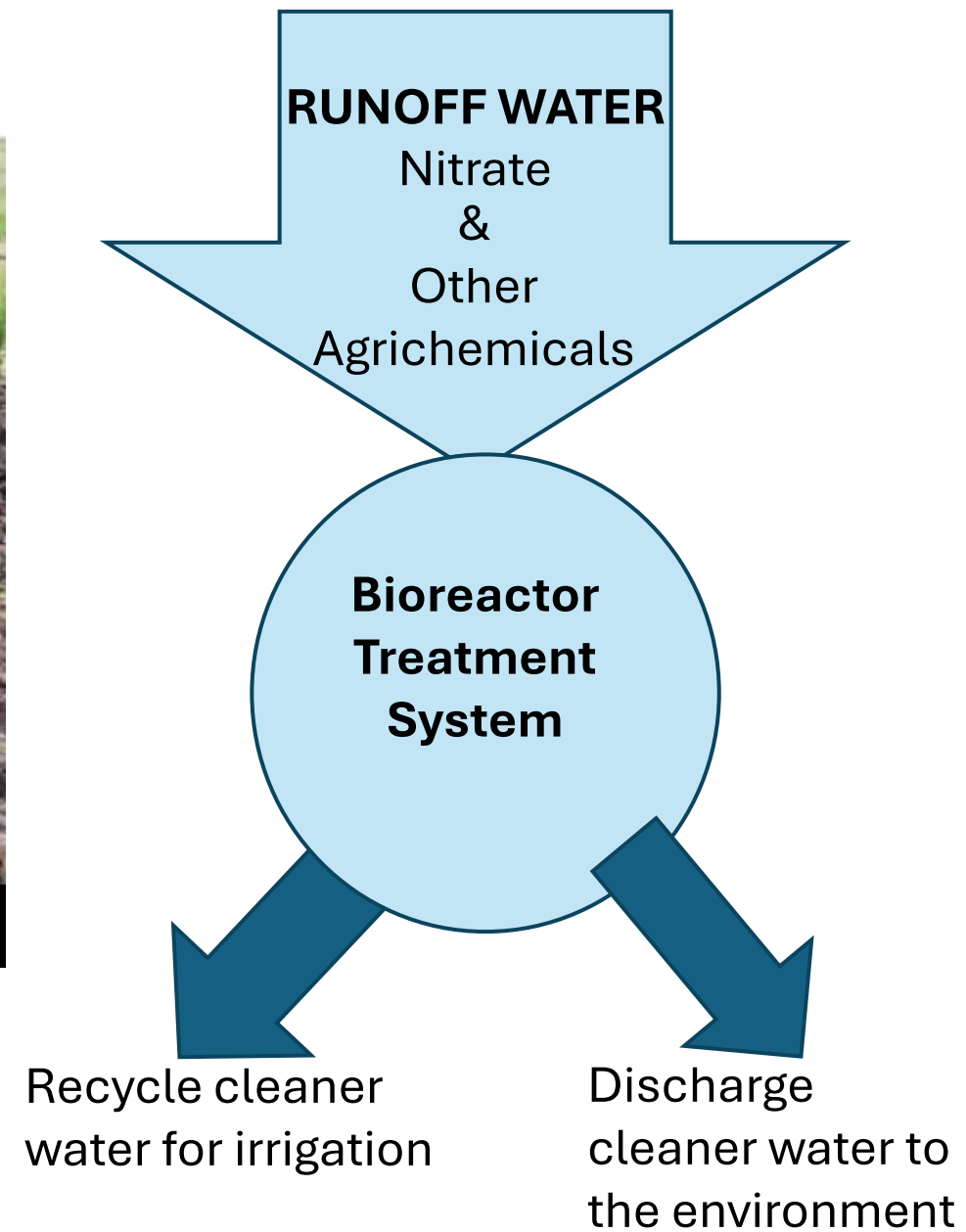
# Woodchip Bioreactors

- Edge of Field: Lined trenches filled with woodchips
- Woodchips are a readily available and inexpensive form of carbon
- Expected life-span 15 - 20 years

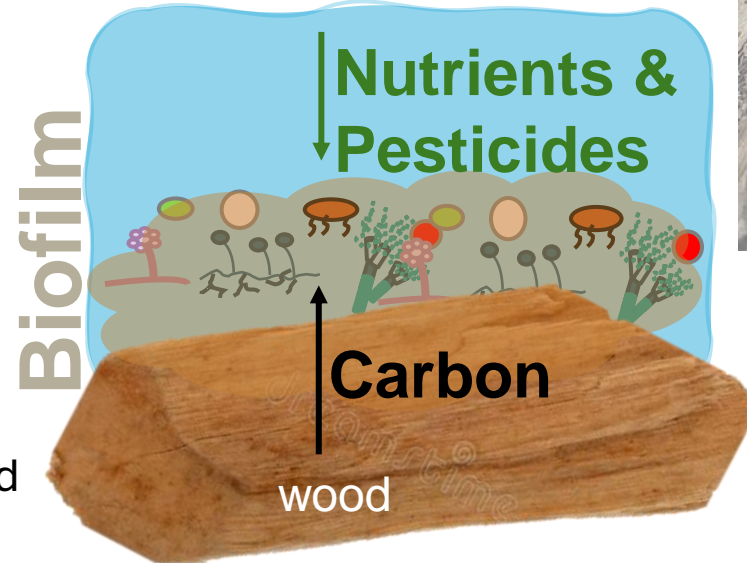




From: Christianson, Laura E. and Helmers, Matthew J., "Wodchip Bioreactors for Nitrate in Agricultural Drainage" (2011). Agriculture and Environment Extension Publications. 85.



# How they work



Microbes convert  $\text{NO}_3$  to nitrogen gasses through denitrification under low oxygen conditions. Microbes will also metabolize some pesticides to less harmful chemicals.

Woodchips provide a food source and “home” for numerous species of microorganisms.

Woodchips adsorb agrichemicals.

Microbes form biofilms that also adsorb agrichemicals.

# Benchtop bioreactor studies

Different hydraulic retention times (HRT)\*

HRT is the average time a unit of water stays in the bioreactor

- Always include 3 HRTs
- 21 minutes to 72 hours

Single and 2-stage systems

- Woodchip / Expanded Shale
- Anaerobic / Aerobic and Aerobic / Anaerobic
- Seeding new bioreactors with woodchips from established bioreactor



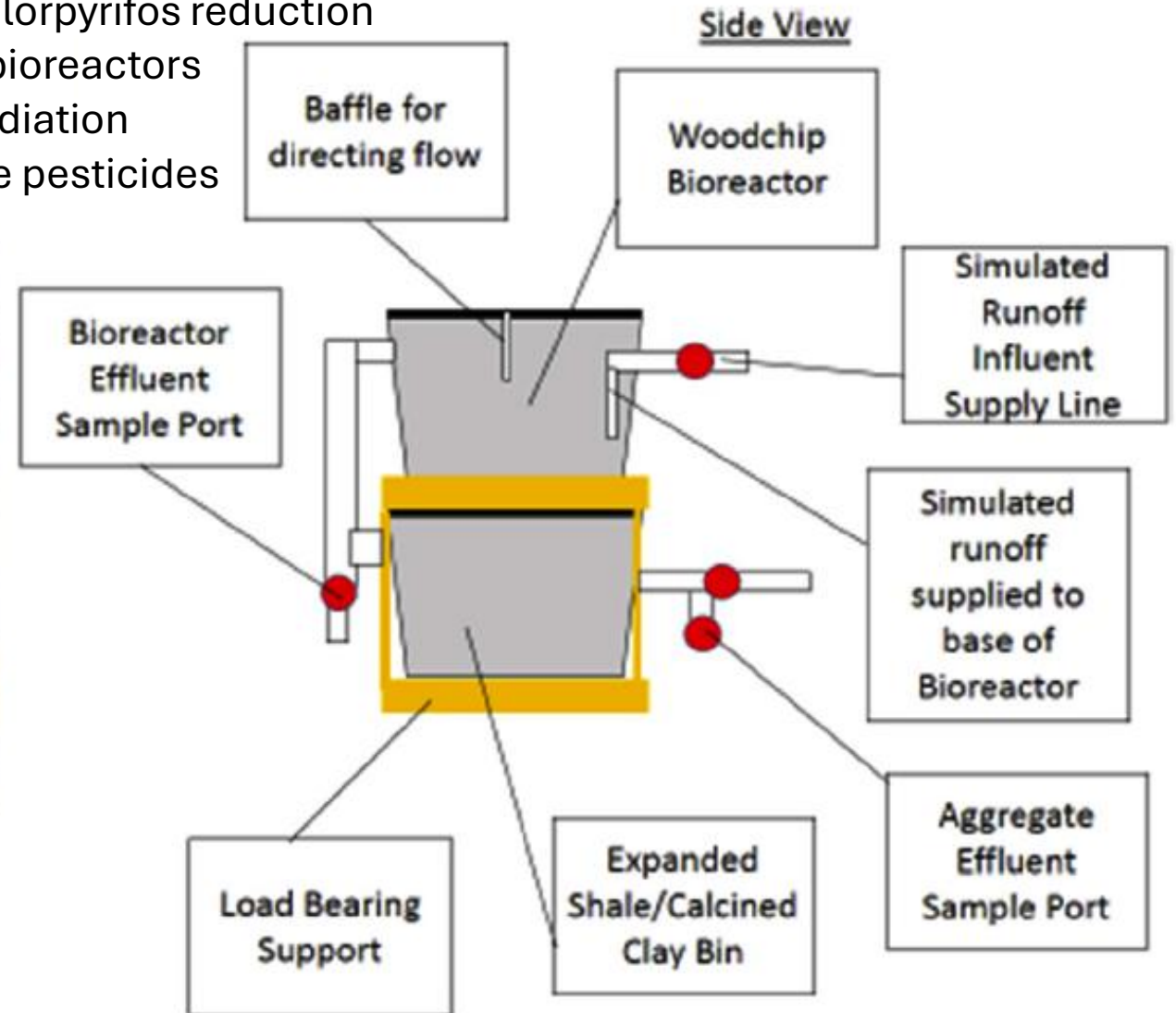
# Previous research from our group

Initial interest in reducing  $\text{NO}_3$  (expected) and  $\text{PO}_4$ , also added chlorpyrifos to test potential toxicity  
Used a 2-stage bioreactor system with haydite, a heat-expanded shale, as 2<sup>nd</sup> stage for  $\text{PO}_4$  remediation  
Found that we had excellent  $\text{NO}_3$ ,  $\text{PO}_4$  and also chlorpyrifos reduction  
1<sup>st</sup> to show pesticide remediation with woodchip bioreactors  
Also found minimal benefit of haydite in  $\text{PO}_4$  remediation  
Since then, have dropped haydite & included more pesticides



Reductions in

Bifenthrin (76%)	Nitrate (99%)
Chlorpyrifos (63%)	Phosphate (87%)
Oxyfluorfen (31%)	





# 21 Minute HRT

**Table 3**

Remediation of nitrate and phosphate in woodchip bioreactors and expanded aggregate filters under a 21 min HRT in 2018. Influent concentrations of nitrate, nitrite and phosphate before addition of pesticides were 12.7 mg L<sup>-1</sup> (±0.3 SE), below detection limit, and 0.7 mg L<sup>-1</sup> (±0.1 SE), respectively, and after addition of pesticides were 18.2 mg L<sup>-1</sup> (±0.6 SE), below detection limit, and 1.5 mg L<sup>-1</sup> (±0.1 SE), respectively.

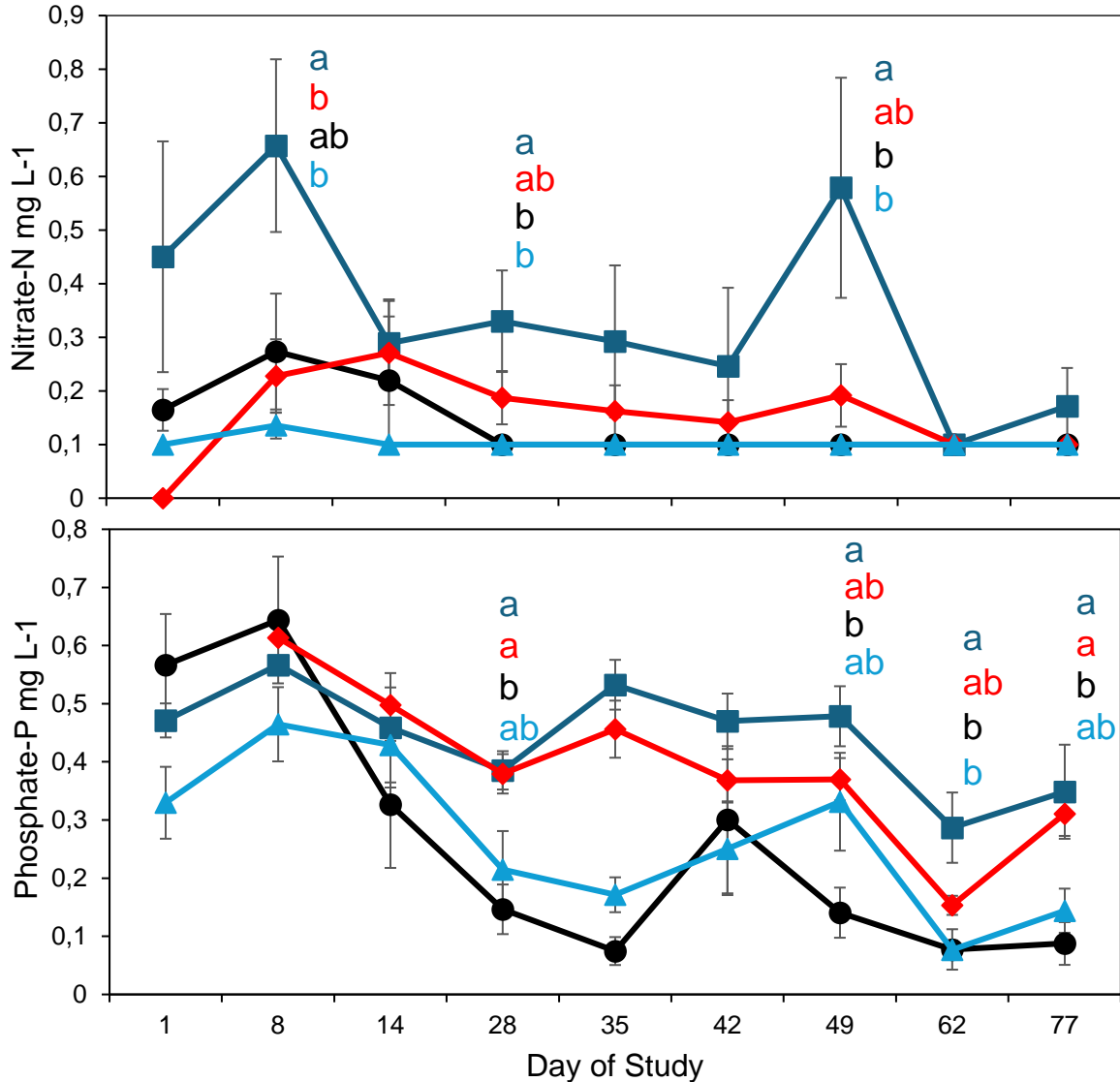
Substrate/Influent Treatment	Nutrient Incubation Period					Post Pesticide Application (Day 35)				
	Nitrate Concentration in Treatment Effluent (mg L <sup>-1</sup> )					Influent NO <sub>3</sub> = 18.2				
	Day 1	Day 6	Day 13	Day 27	Day 34	Day 41	Day 48	Day 55	Day 62	Day 69
Woodchips - Nutrients Only	16.1 a	14.7 a	12.0 a	11.1 a	11.4 b	22.6 a	18.9 a	22.5 a	17.4 a	17.4 a
Woodchips - Nutrients + Pesticides	.	Influent NO <sub>3</sub> = 12.7			.	23.2 a	19.0 a	22.9 a	17.9 a	16.4 ab
Shale - Nutrients Only	12.6 b	12.7 b	13.2 a	11.2 a	13.4 a	20.6 ab	18.5 a	19.6 b	18.8 a	16.2 ab
Shale - Nutrients + Pesticides	.	.	.	.	.	20.4 b	18.7 a	20.4 b	20.4 a	15.3 b
	Phosphate Concentration in Treatment Effluent (mg L <sup>-1</sup> )					Influent PO <sub>4</sub> = 1.5				
Substrate/Influent Treatment	Day 1	Day 6	Day 13	Day 27	Day 34	Day 41	Day 48	Day 55	Day 62	Day 69
Woodchips - Nutrients Only	1.28 a	0.75 a	0.54 a	1.02 a	0.63 a	1.47 a	1.77 a	1.67 b	1.67 a	2.23 a
Woodchips - Nutrients + Pesticides	.	Influent PO <sub>4</sub> = 0.7			.	1.41 a	1.86 a	1.45 ab	1.68 a	2.41 a
Shale - Nutrients Only	1.00 a	0.73 a	0.63 a	1.07 a	0.72 a	1.74 a	1.49 a	1.84 a	1.91 a	2.11 a
Shale - Nutrients + Pesticides	.	.	.	.	.	1.53 a	1.75 a	1.89 a	1.98 a	2.17 a

Means followed by the same letter within a given column by ion are not significantly different at p = 0.05. Woodchip bioreactors and expanded shale filters had 20 replications during the incubation period, respectively, and following pesticide application, each substrate/influent combination had 10 replications each.

Takeaway: very short HRT had little effect on nutrients, effluent nearly the same and sometimes higher than the influent.

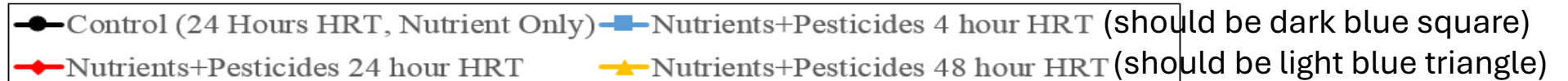
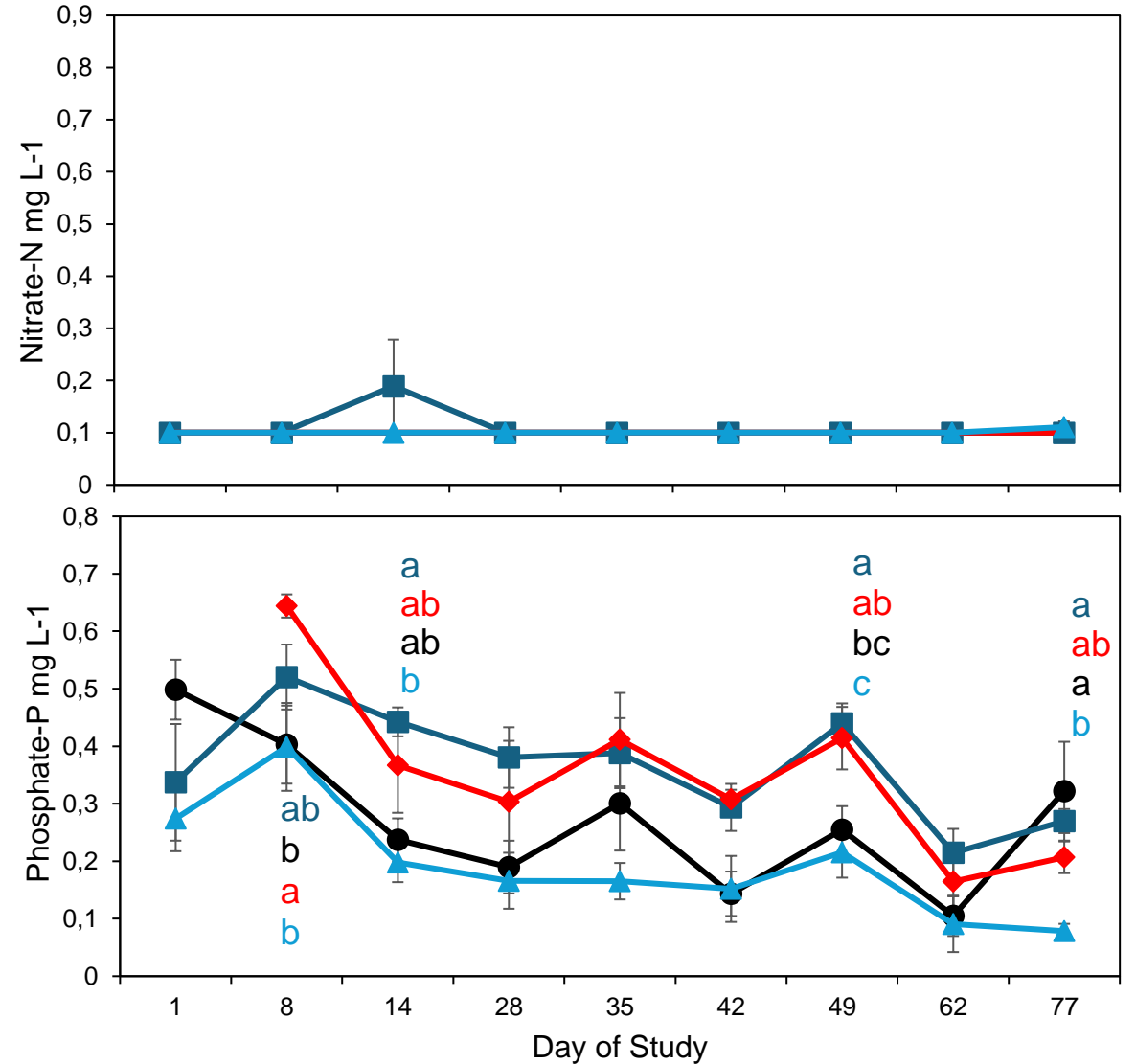
### Woodchip Stage

Influent Concentration:  $\text{NO}_3 = 3.67 \text{ mg L}^{-1}$   $\text{PO}_4 = 0.67 \text{ mg L}^{-1}$



### Haydite Stage

Influent Concentration for haydite stage was woodchip effluent concentration



Influent concentrations:

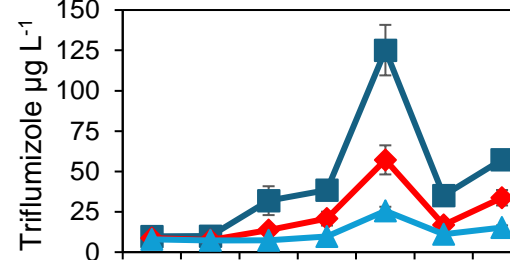
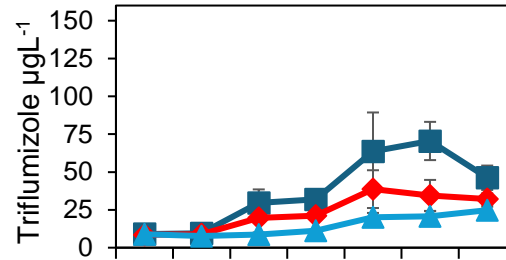
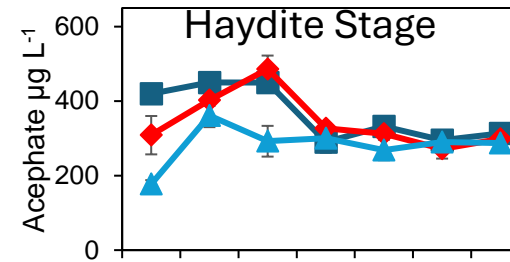
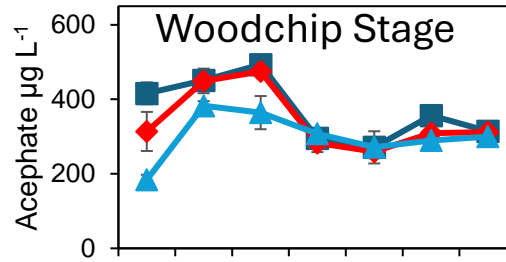
Acephate 318  $\mu\text{g L}^{-1}$

Triflumizole 151  $\mu\text{g L}^{-1}$

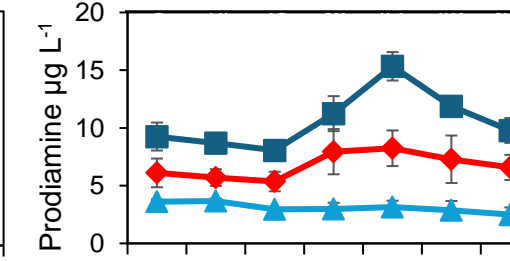
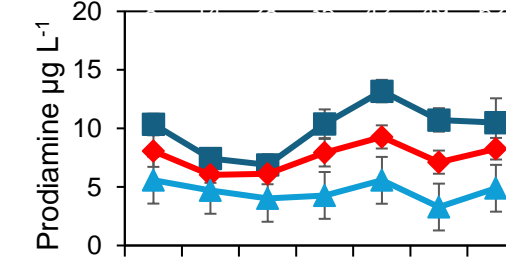
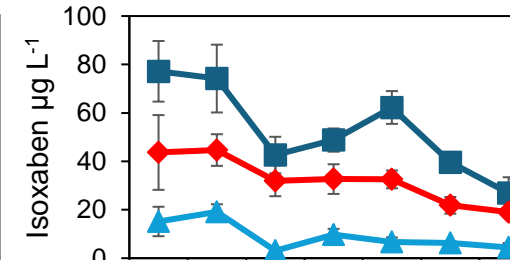
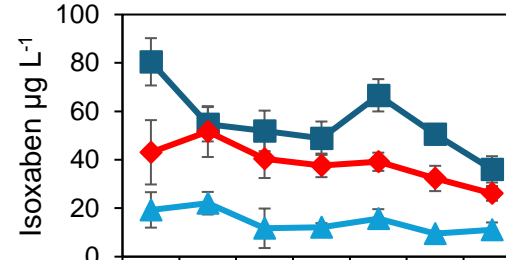
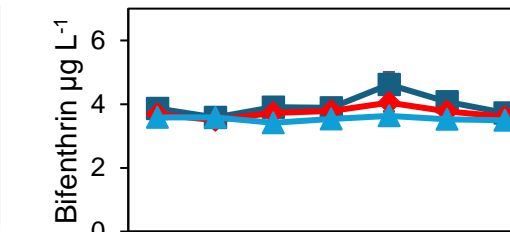
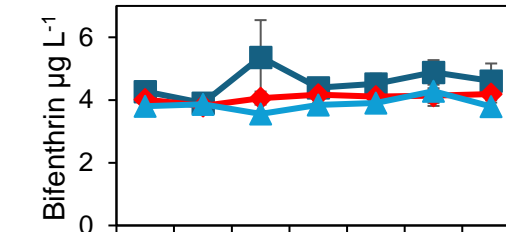
Bifenthrin 6.5  $\mu\text{g L}^{-1}$

Isoxaben 110  $\mu\text{g L}^{-1}$

Prodiamine 19.8  $\mu\text{g L}^{-1}$



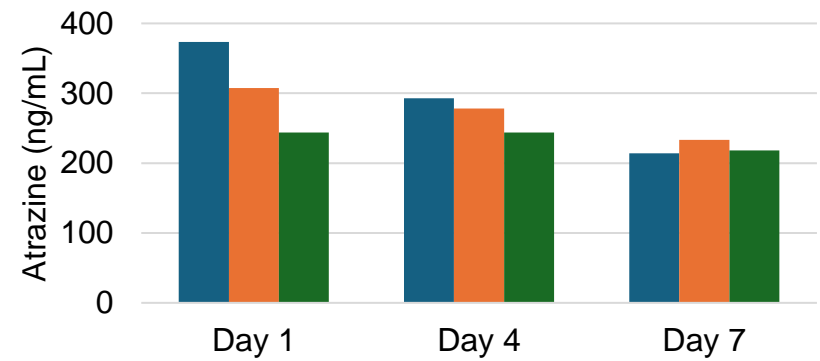
Influent concentrations for the haydite stage was the effluent concentration from the woodchip stage



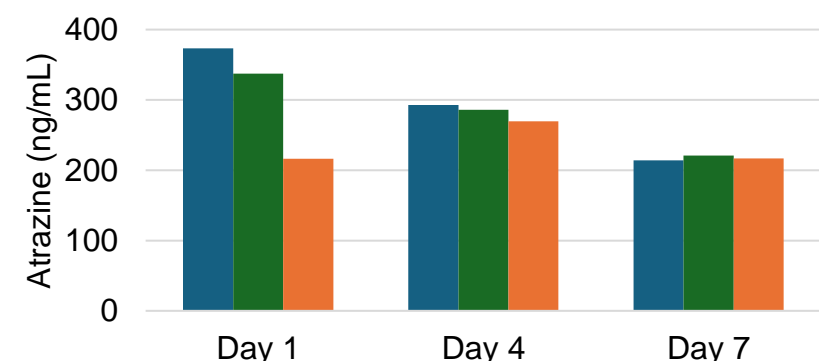
(should be dark blue square) — 4 Hour HRT — 24 Hour HRT — 48 Hour HRT (should be light blue triangle)

**Inlet**   **Aerated Stage**   **Unaerated Stage**

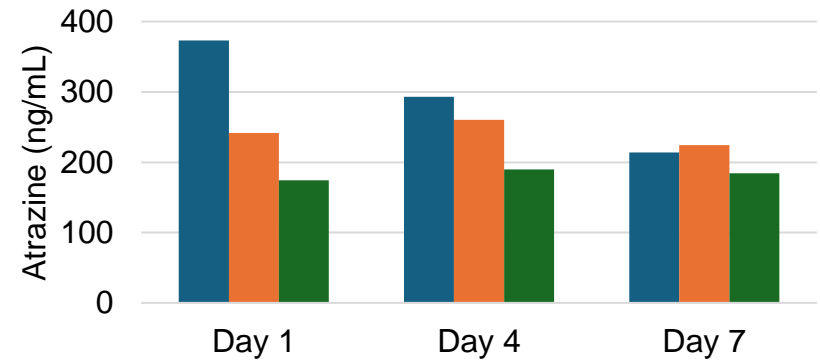
12 HRT



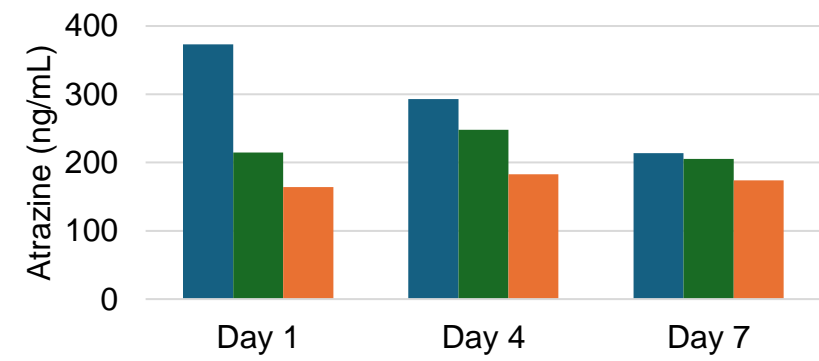
12 HRT



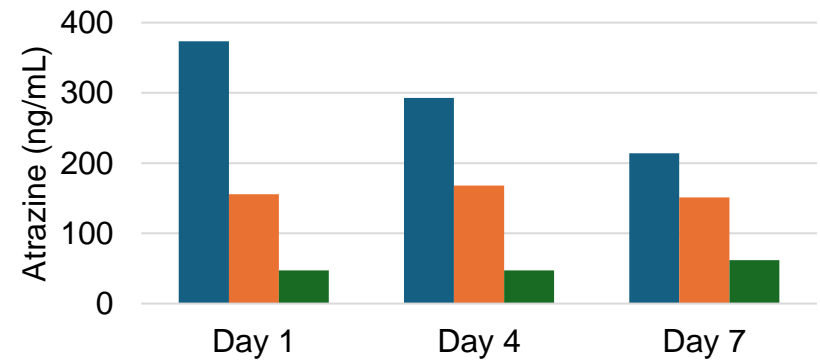
24 HRT



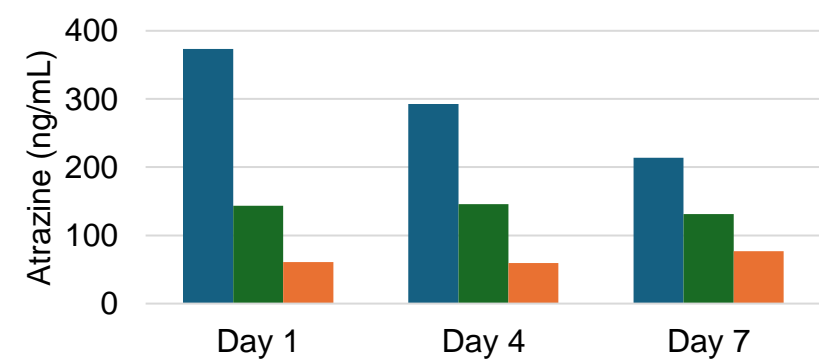
24 HRT



48 HRT



48 HRT



# Summary from bench-top bioreactors

- Hydraulic Retention Time Single Stage Bioreactors
  - HRTs < 4 hours did not affect  $\text{NO}_3$  and  $\text{PO}_4$  but still reduced pesticides
  - HRTs > 4 hour reduced  $\text{NO}_3$ ,  $\text{PO}_4$  and pesticides
  - As HRT increased, reduction in concentrations of agrichemicals increased (more efficient)
  - As HRT decreases, more water is treated, thus greater reductions in daily load occurred (more effective)

Example for 1300 L bioreactor:

HRT (hours)	Decrease in	
	Concentration ( $\text{mg L}^{-1}$ )	Load ( $\text{g day}^{-1}$ )
12	157	122
24	209	82
48	312	61



- Seeding with different % woodchips from established bioreactor - in process, no results yet.
- 2-stage Bioreactor Systems
  - Using haydite (heat expanded shale) had minimal improvement in  $\text{PO}_4$  or pesticide reduction – no longer use this system
  - Order of anaerobic / aerobic stage – in process, having aerobic as stage 1 seems better currently.

# Commercial-scale Woodchip Bioreactors

- Grower with 9 ha of greenhouse production
- Using bioreactors to treat 1.15 ha flood-floor greenhouse range
- 2022: 1-stage 1136 L anaerobic bioreactor, 31-minute HRT
- 2023: 1-stage 1136 L (31-minute HRT) and 2271 (70-minute HRT)
- 2024: 2-stage for each HRT:
  - 31-minute HRT 1<sup>st</sup> stage anaerobic, 2<sup>nd</sup> stage aerobic
  - 70-minute HRT 1<sup>st</sup> stage anaerobic, 2<sup>nd</sup> stage aerobic



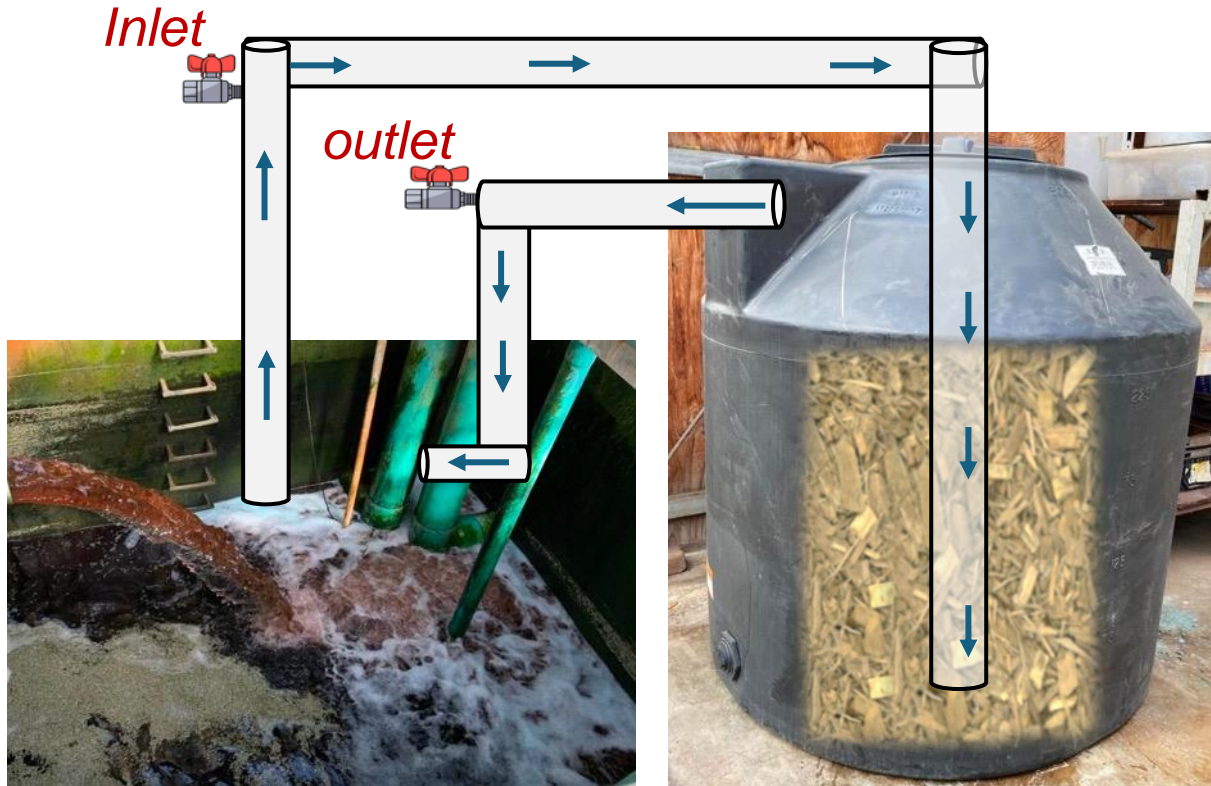


Pumped into 1136 L woodchip bioreactor, 31-minute HRT  
Returns to underground recycling tank gravity drainage

Flood floor irrigation drains into underground capture tank



# Based on benchtop woodchip bioreactors

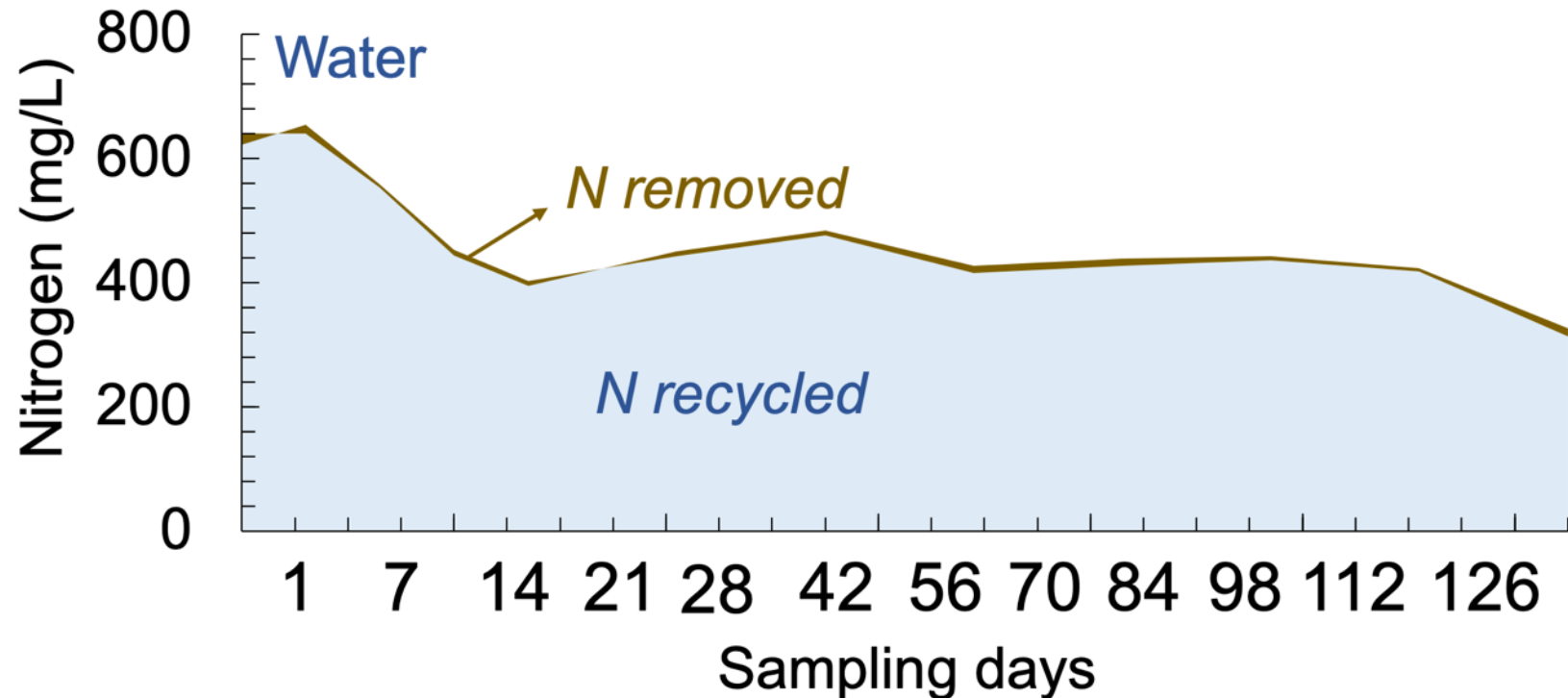
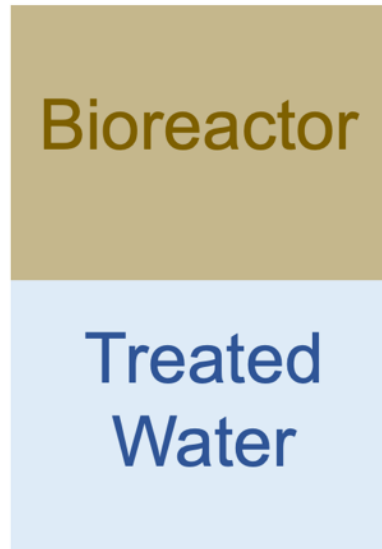


- Longer retention time **removes** nutrients and pesticides.
- Shorter retention time **recycles** nutrients while **removing** pesticides.



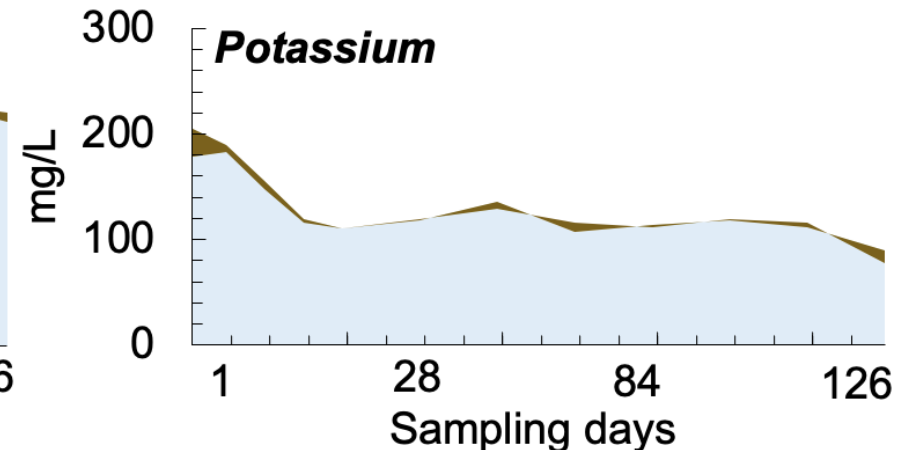
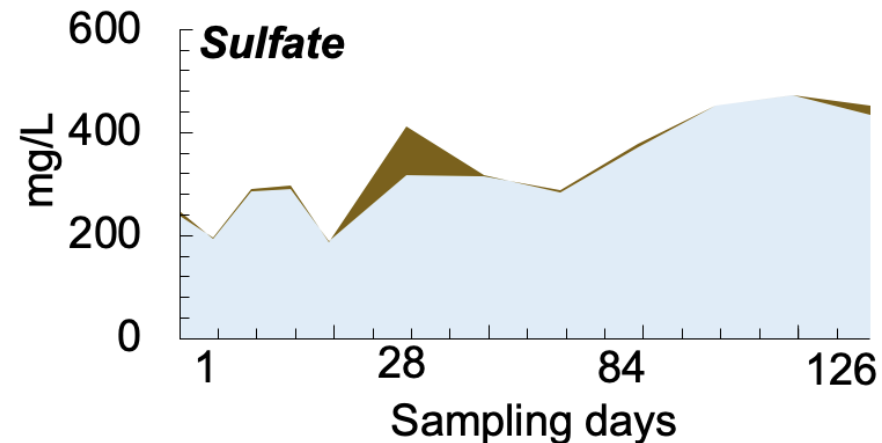
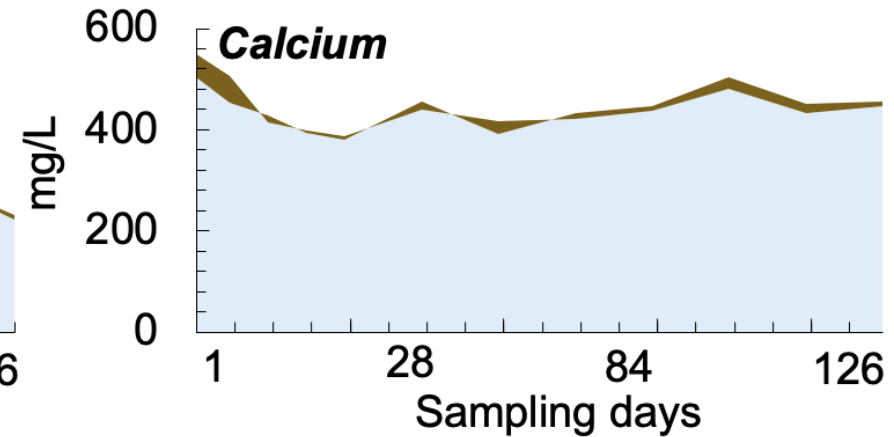
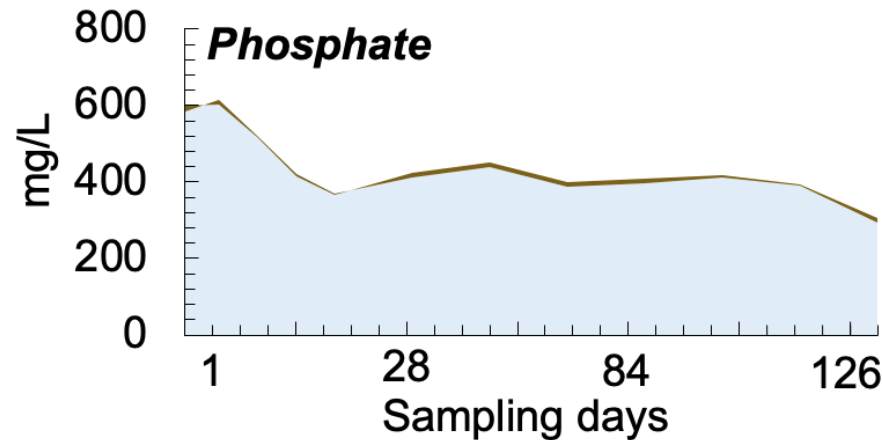
# 2022 31-minute HRT woodchip bioreactor

- Fertilizers (N, P, other nutrients) are being recycled
  - 99% total nitrogen is recycled



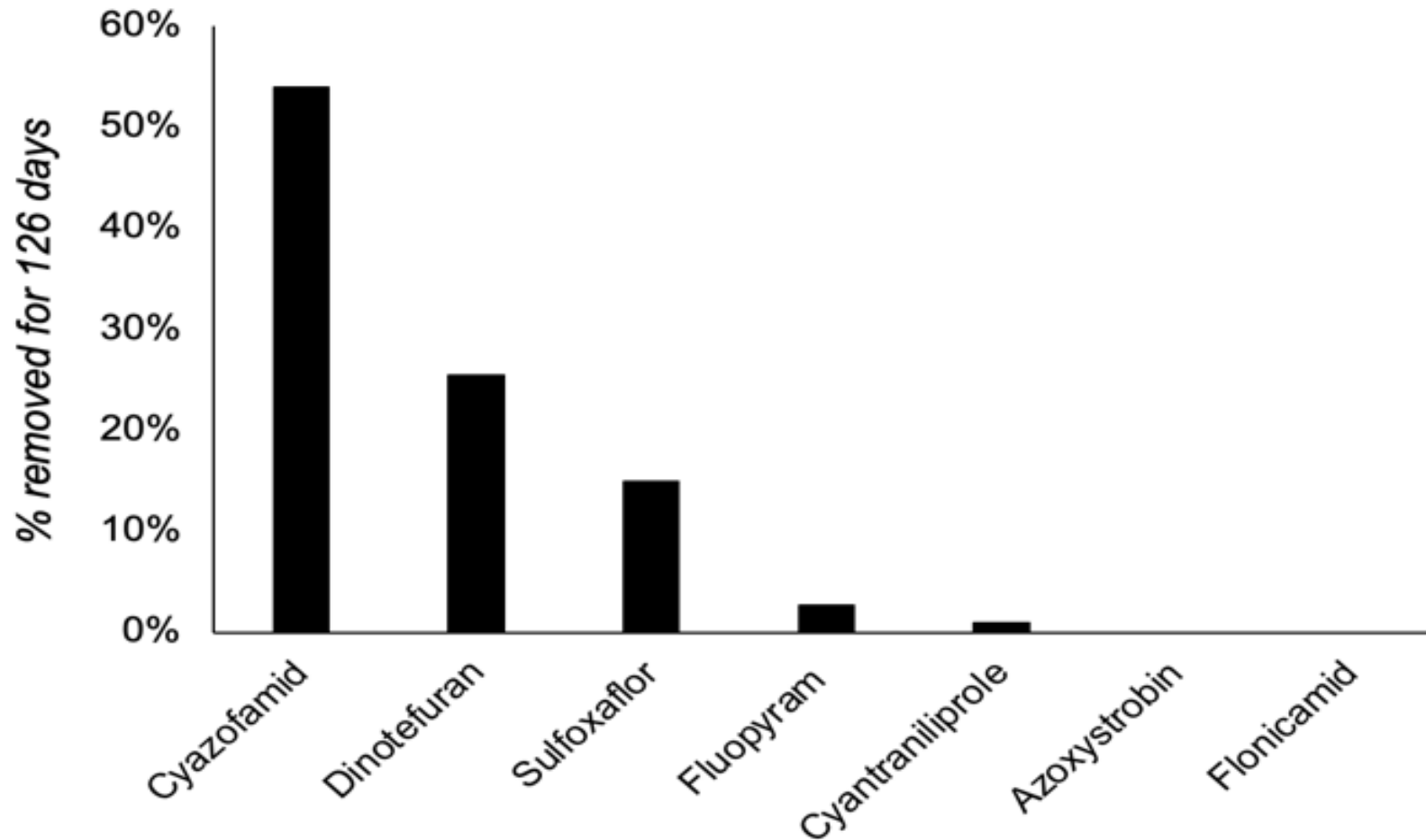
# 2022 31-minute HRT woodchip bioreactor

- Fertilizers (N, P, other nutrients) are being recycled
  - 99% total nitrogen is recycled
  - Other nutrients were recycled



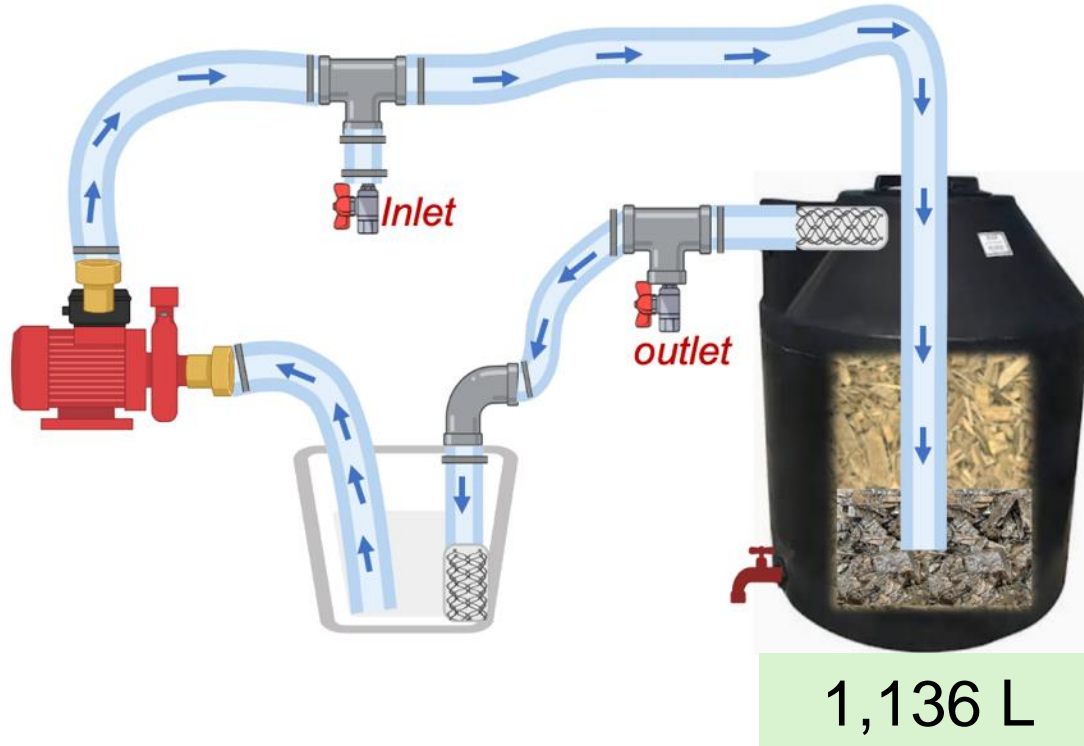
# 2022 31-minute HRT woodchip bioreactor

- 15-50% pesticide removal from the recycled water.



Grower used 86 different pesticides in this range in 2022, these were the only ones we found. However, further removal of pesticides is desired.

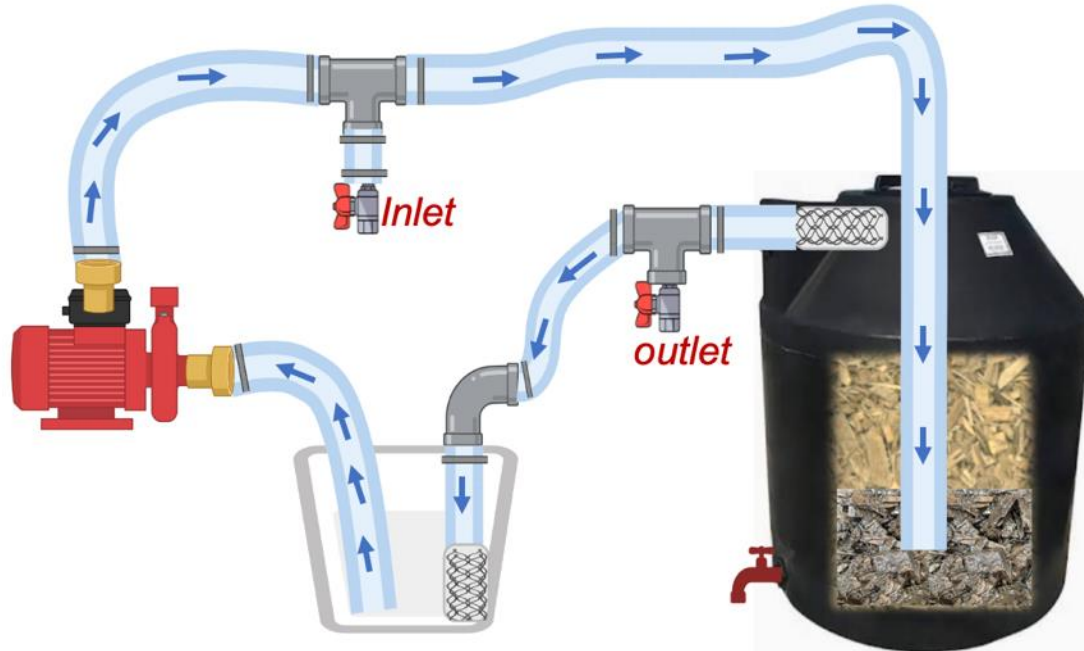
## 21-minute HRT



- Repeat experiment.
- Mix old + new woodchips (*acclimate biofilms*).

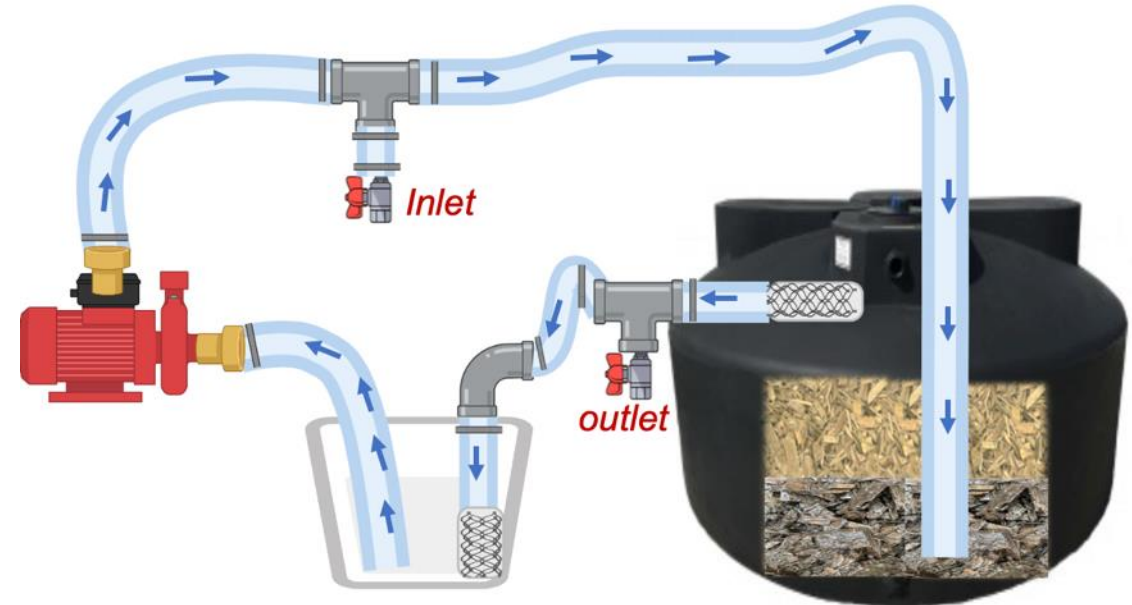
2023

## 21-minute HRT



1,136 L

## 70-minute HRT



2,271 L

- Repeat experiment.
- Mix old + new woodchips (*acclimate biofilms*).
- Increase retention time to further remove pesticides.

# 2024



# Summary/Conclusions

- Shorter HRTs remove larger amounts of agrichemicals per day but longer HRTs reduce concentration more.
- Woodchip bioreactors are effective without addition of mineral stage (e.g. haydite).
- Woodchip bioreactors can be used to remove phosphates.
- HRT can be modified depending on fate of water being treated:
  - Recycled water: very short HRTs to remove pesticides but retain nutrients.
  - Released water: Longer HRTs (> 4 hours) to remove majority of agrichemicals.
  - Pesticides used: more recalcitrant pesticides may need longer HRTs
- Too early to tell if
  - 70-minute HRT will remove more pesticides than 21-minute HRT
  - Which stage, if any, should go 1<sup>st</sup>- anaerobic or aerobic

# Lifespan of Bioreactors

- Pit-style bioreactors can last 15-20 years. Longevity is increased if the woodchip zone remains saturated in water.
- As woodchips are consumed by bacteria, additional loads can be added in directly.
- Size of bioreactors can be scaled to meet water quantity needs, remediation goals, and site-specific considerations



# Tank-style Bioreactors

- Are inexpensive (versus digging large pits)
  - Our 2,271 L bioreactor cost less than \$1,200 US, including woodchips and delivery
- Can easily be installed in existing facilities
- Can have multiple tanks separately (to treat different water sources) or in series to have more than one treatment (HRT, oxygenation, matrix, etc.)
- Tank sizes are available from less than 1,000 L to 3.7 million L
- Are portable so they can be moved to sites where needed
- Can be dispersed rather than concentrated in a particular area

# Acknowledgments

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