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#UMNdriven

2022 Onsite Wastewater MEGA-Conference

Evaluation and Application of Biochar and Iron-Enhanced Sands in Septic Systems

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Water Resources Center

Department of Bioproducts and Biosystem Engineering

Disclaimer

- The materials presented by Chia-Yang Chen represent my own opinions, and do NOT reflect the opinions of NOWRA.

Outline

-Introduction

-Literature Review

-Experimental section

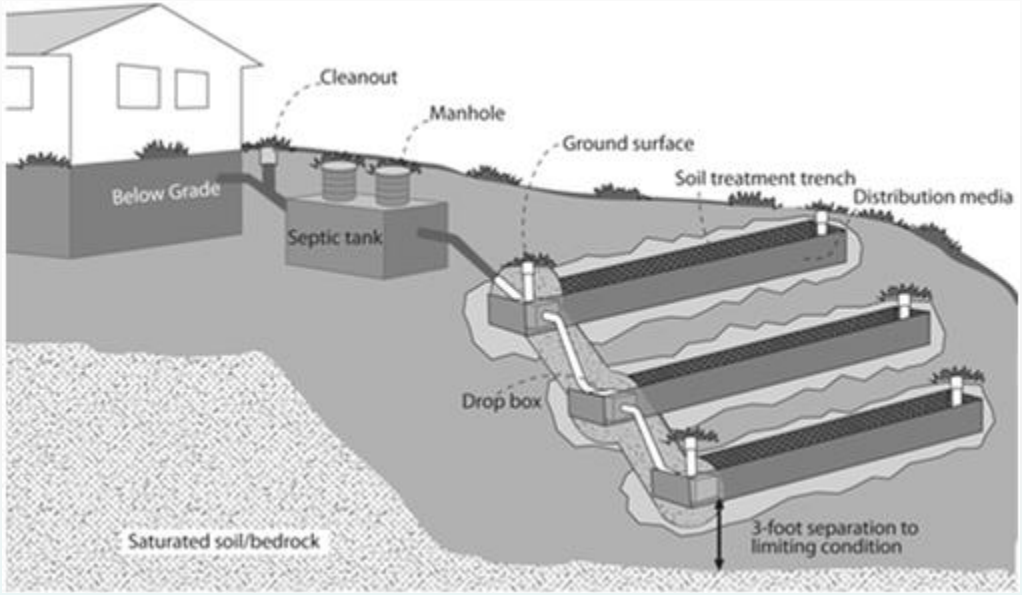
-Results and Discussion

-Conclusions and Future work

Introduction

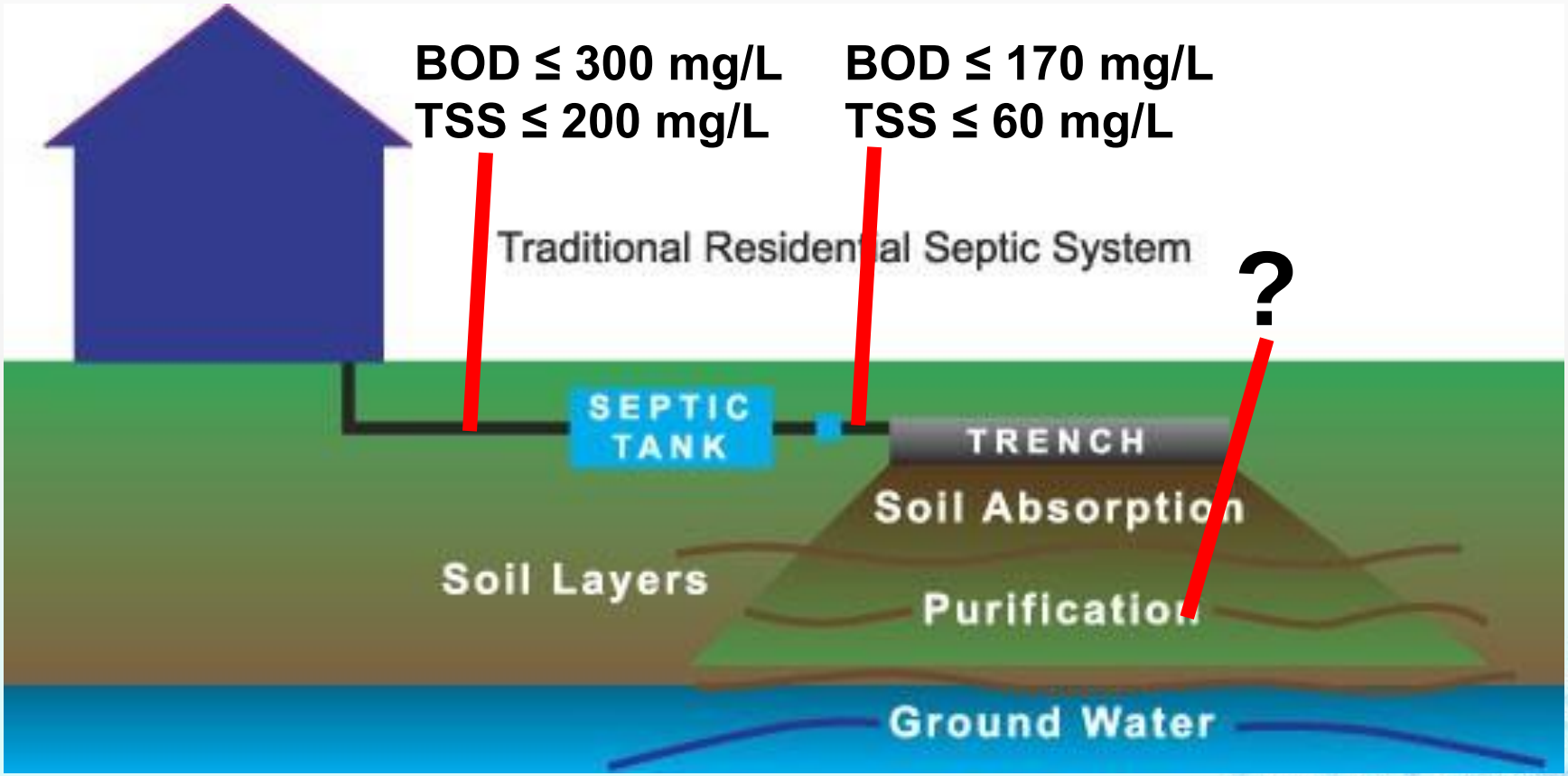
Septic system in Minnesota

- 600,000→40 billion gallons/year
- 25% →shoreland



- Non-point source to release nutrients and bacteria (MPCA, 2021)

Septic System



http://anytimesepticok.com/services/subsurface-systems/

Papers summary

sand filtration for septic tank effluent

Sand	Important properties	Operating condition	Wastewater (mg/L)	Outcomes
Commercialized Sand	**Effective size** 0.45 mm **Sand Depth** 24 inches	Intermittent 0.56-1.68 m/d (Trial 1) 0.2 m/d	Septic tank effluent BOD: 120 COD: 289 TSS: 45	After sand filtration BOD: 22-25 COD: 77-85 TSS: 13-22 : 7-9 3.6-16.0 1.0-5.7 5.9-8.2 +3 numbers/100 ml +4 numbers/100 ml
Sand				d filtration 28 (Trial 1) 40 (Trial 2) 6 (Trial 1) 28 (Trial 2) 3.6 (Trial 1) 3.0 (Trial 2)
Coarse sand **Fine sand** **Glass sand**				d filtration viruses 5.2 E+3 U/L
River sand	0.8 0.4 1.1 4.75 (G			iltration 21-27 40-47 y: 4-5 NTU 383 µS/cm 51-7.62 2.0-3.7 E+2 /100 ml 5.3-9.1 E+3 /100 ml
Sand		4 hours/cycle	TSS: 37 pH: 4.85	d filtration : 156 TSS: 22 pH: 5.91
Silica sand **Crushed lava rock**	**Size** 0.5-2.56 mm (Crushed lava rock) 0.5-2.56 mm (Silica Sand)	**Constant** 20 cm/d 40 cm/d	**Settled greywater** pH: 7.2 DO: 2.2 BOD: 1125	After filtration (removal efficiency) Column 1 BOD: 61-67 COD: 70

Sand filtration

Good ✓

Organic matter (~80%)

Turbidity

Bad ✗

Nutrients

Bacteria

Biochar and Iron materials

- **Biochar**
  -High surface area
  -Homogeneous
  -Grindability

- **Iron materials**
  -High surface area
  -High affinity to nutrients

https://www.connellygpm.com/zero-valent-iron

Papers summary
Biochar application in wastewater

Materials	Pyrolysis condition	Important properties	Wastewater (mg/L)	Outcomes
Pine wood	1000 ℃ 60 mins	**BET:** 152.3 m^2/g **Particle Size:** 4.8-8 mm^3	**Brewery** COD: 1243 PO_4: 18 NH_4: 24 TSS: 320	The higher removal rate is achieved by biochar instead of activated carbon. The biochar removal rate of pollutants is 94%, 90%, 87%, and 82% for COD, PO_4, NH_4, and TSS, respectively.
Commercialized*2 Sand*3	900-1000 ℃ 550 ℃	**BET:** 537 m^2/g 136 m^2/g **Particle Size:** 0.15-1 mm **CEC:** 10.57 cmol/kg 13.63 cmol/kg **Carbon:** 80.1 % 81.7 %	**Synthetic stormwater*2** DOC: 0-15 NH_4: 1-4 NO_3: 1-6 DON: 1-2 E. coli: 0-10^7 CFU/100ml	After adding 30% (volumetric basis) of biochar, the TAN removal ratio is increased from 78.3% to >99%. The removal ratios of DON, TN, and DOC are also significantly enhanced by 5-18%. The result of E. coli doesn't have significant change before/after biochar addition. However, the NOx (NO_2 and NO_3) will be increased after applying biochar due to more captured TAN and the following nitrification.
eupatorium adenophorum	300-600 ℃	**BET:** 11.4 m^2/g **CEC:** 19.5 cmol/kg **Carbon:** 69-76%	**Synthetic** NH_4: 5-100 PO_4: 5-100	The removal ratio of co-adsorption of ammonia and phosphate is significantly improved after pyrolysis. The low pyrolysis temperature shows better performance on the adsorption. The pseudo-second-order kinetics and Langmuir-Freundlich model fits the adsorption performance. Maximum uptake amount are 2.32 mg P/g and 1.909 mg N/g)
				Five percent of biochar (in weight basis) increases 3 order of magnitude E. coli

Papers summary
IES application in wastewater

Iron type	Mixing Percent (%)	Important properties	Wastewater (mg/L)	Outcomes
Fe (0)	0.3-5% (column) 7.2 and 10.7% (field)	**Iron** 87-93% **Carbon** 2.85-3.23% **Particle size** <4.75 mm	**Synthetic stormwater** 0.233-0.531 mg PO_4-P/L **Field study** 0.027-0.14 mg PO_4-P/L	In the synthetic stormwater experiment, it's clear that 100% sand has no impact on the phosphate retain. On the contrary, 79% and 88% of removal efficiency is got from 2% and 5% of iron filling, respectively. For the real field application, 85-90% of phosphate can be retained by the 7.2-10.7% IES.
Fe (0)	50%	**Particle size** <0.43-0.60 mm	Doping 4 log CFU/mL Into **DI and pond water**	The 50% IES presented high removal ratio on the E. coli in DI water. After 35 days, the removal ratio remains 95.58%. The removal ratio of 50% IES reduces sharply when using pond water. The removal efficiency reduces from 98.99% (Day 1) to 43.93% (Day 35), revealing that the turbidity and conductivity would have some impacts on the E. coli removal.
Fe (2+)	0-150 mg/L	-	**Synthetic wastewater** COD: 432-449 TN: 181-189 TP: 18-20	Greater than 85% COD removal efficiencies could be achieved by all the treatments and no significant difference before/after iron addition. The TN removal efficiency will be higher by 5-15% when doping high iron content (50 mg/L). While all the removal efficiency of NO_3-N is over 90%, the NH4-N removal efficiency is around 60% under high iron content for HRT>1d.
				The removal efficiency of 95% can be

Biochar and Iron materials

Sandy Soil

BOD/COD	Turbidity	NH_4	NOx	TP/PO_4	Bacteria
B	A	B	C	C	B

Biochar

BOD/COD	Turbidity	NH_4	NOx	TP/PO_4	Bacteria
A	B	A	C	B	A

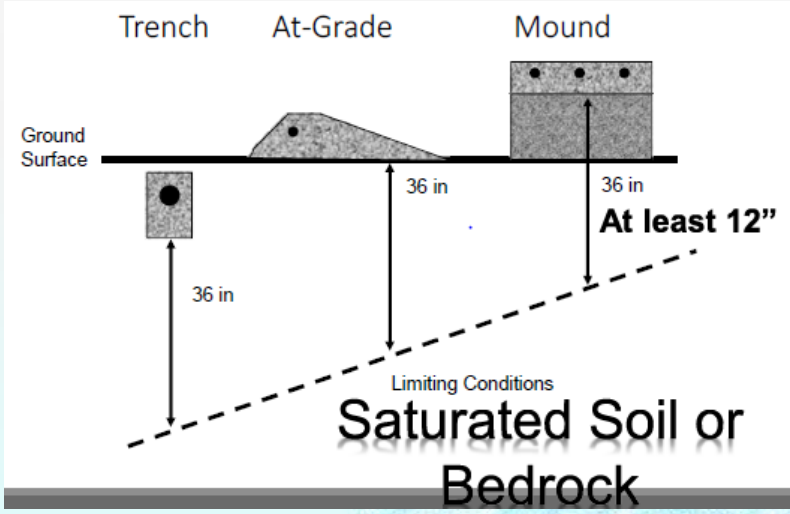
Iron materials

BOD/COD	Turbidity	NH_4	NOx	TP/PO_4	Bacteria
C	-	C	A	A	B

Evaluate under the same basis - uptake amount/adsorbent dosage

Purpose

- Soil-Biochar-IES mixture
- Real septic tank effluent
- Best material
- Applied dosage amount
- Big goal – local economy and well-being



M&M

Real Septic tank effluent

N=3	Mean
pH	7.27
EC	615.5
DO	1.1
TSS	57.5
TDS	485.5
TS	540.5
BOD	167.5
Total Nitrogen	75.1
Nitrate	3.44
Nitrite	N.D.
TKN	71.2
Total Phosphorus	7.835
Phosphate	6.185
Fecal Coliform	98000

Batch test

- Sand - ASTM **C33**

  Biochar & iron powder – **Different material types**

- Dosage amount – **0.5**, **1**, **2**, **5**, **10** g/50 ml wastewater

- **Covered Flask = 50 ml wastewater + adsorbent**
- **Shaker for 24 hr**
- **Sample and analyze**

Biochar & Iron materials

- Minnesota based – **Black ash** and **Red pine**
- Commercialized
  - Biochar DG
  - Biochar Pure
  - Naked Char
  - Terra Char – **softwood Pine**
    – softwood Chunk
    – hardwood powder

- Iron – **IES**, **ZVI**, and **iron tailings**

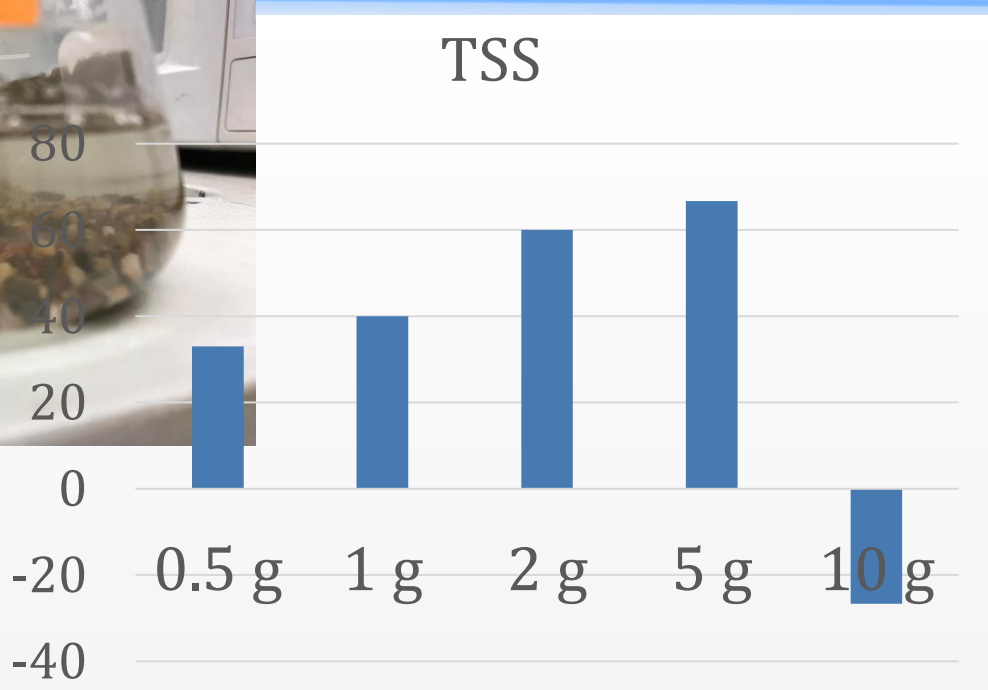
Contaminants - Analysis

- Solids
  TSS
- Organic matters
  BOD
- Nutrients
  Nitrogen – Total Nitrogen (TKN+NOx)
  Phosphorus – Total Phosphorus
- Bacteria
  Fecal Coliform

Results & Discussion

Batch tests

- **C33 batch test – applied dosage**
- **Biochar – different materials**
- **Iron – different materials**
- **Biochar – applied dosage**
- **Iron – applied dosage**



Removal efficiency ↑

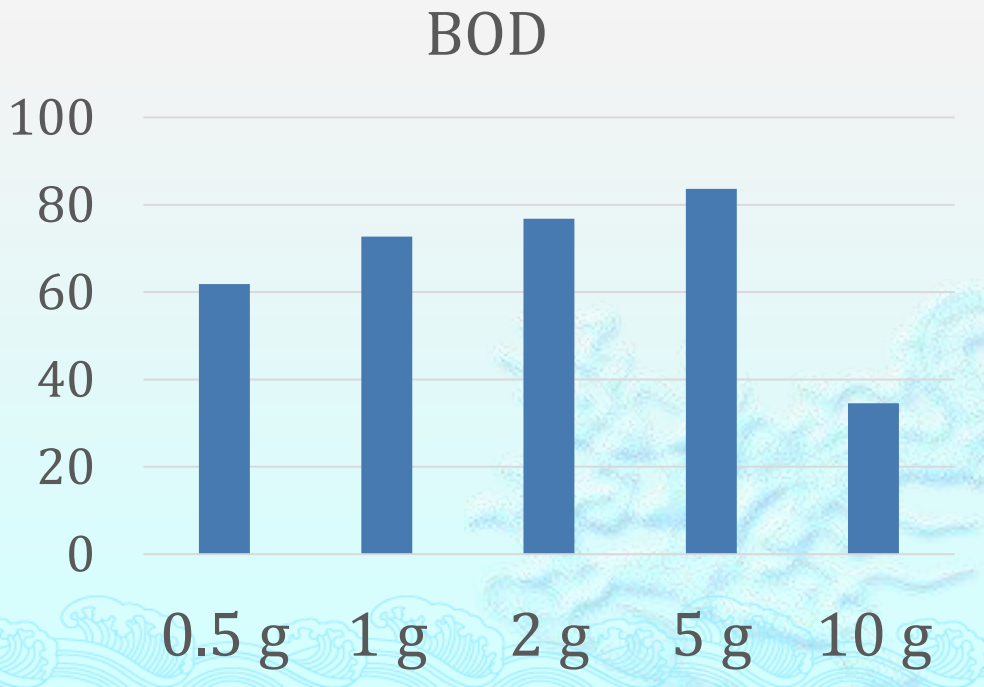
Dosage ↑ until 5 g

10 gram→turbidity

T-test for dosage

p-value < 0.005

5 gram!!



Nutrients

Nitrogen

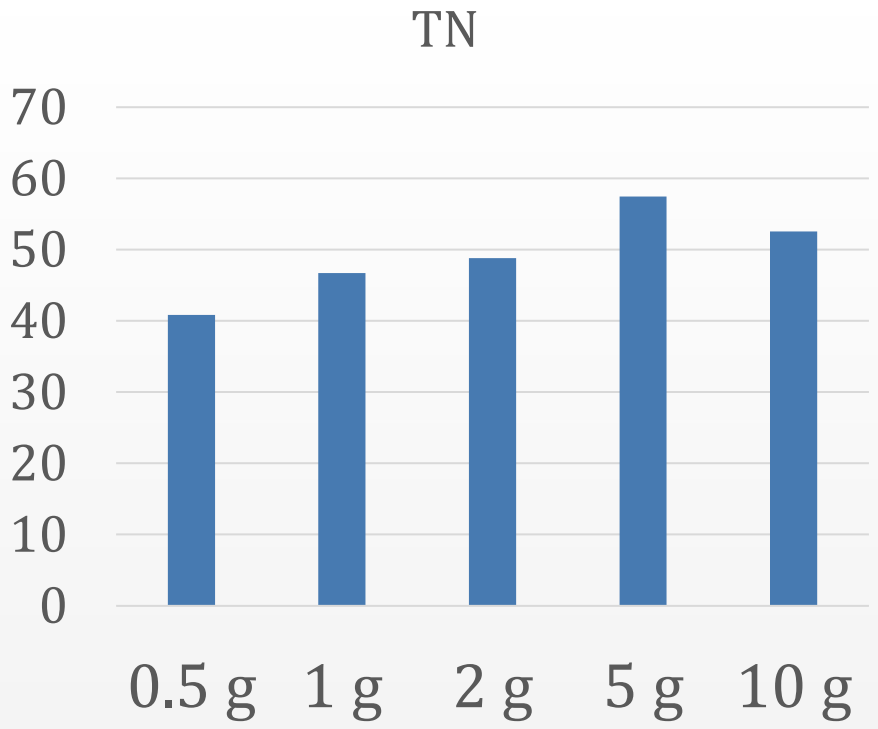
5 gram is still the best!

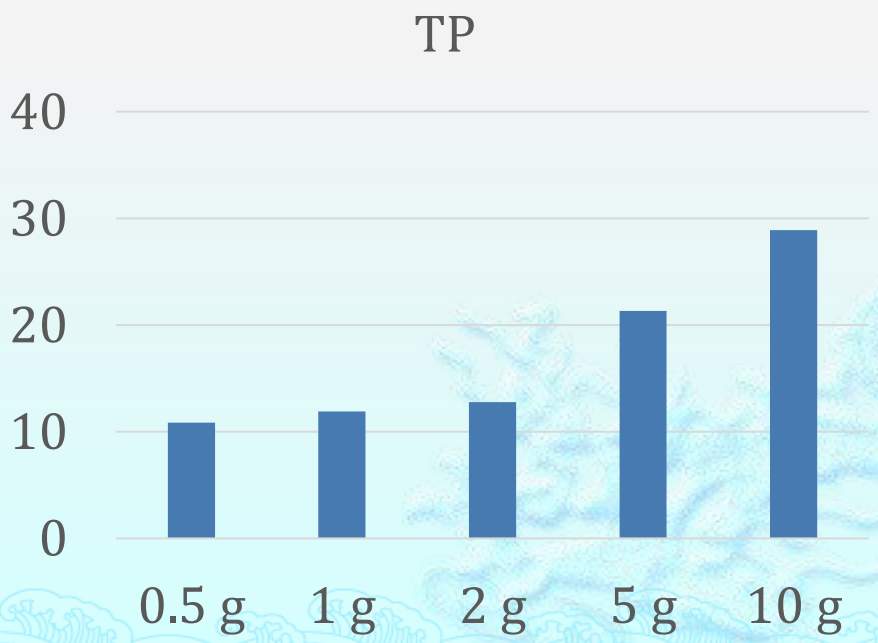
Phosphorus

Isn't affected by C33 release

Removal efficiency ↑

Dosage ↑



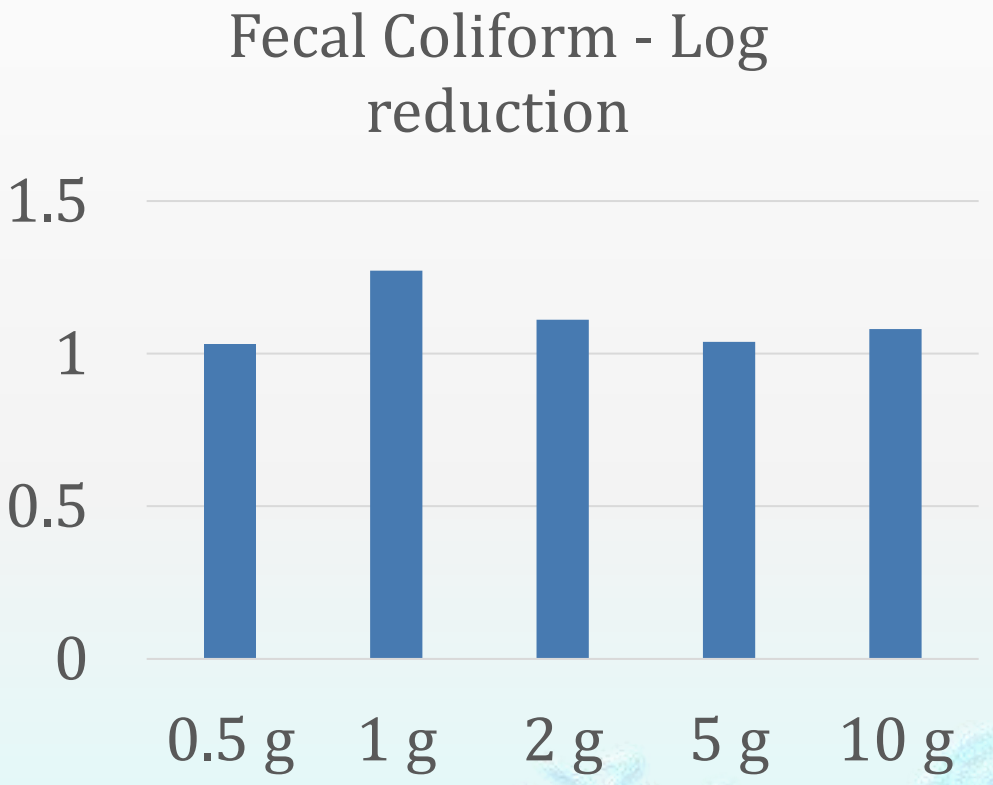


Fecal Coliform

1-1.3 log reduction.

No significant difference.
p-value > 0.005

0.5 grams
If
Target contaminant→Fecal



Batch tests

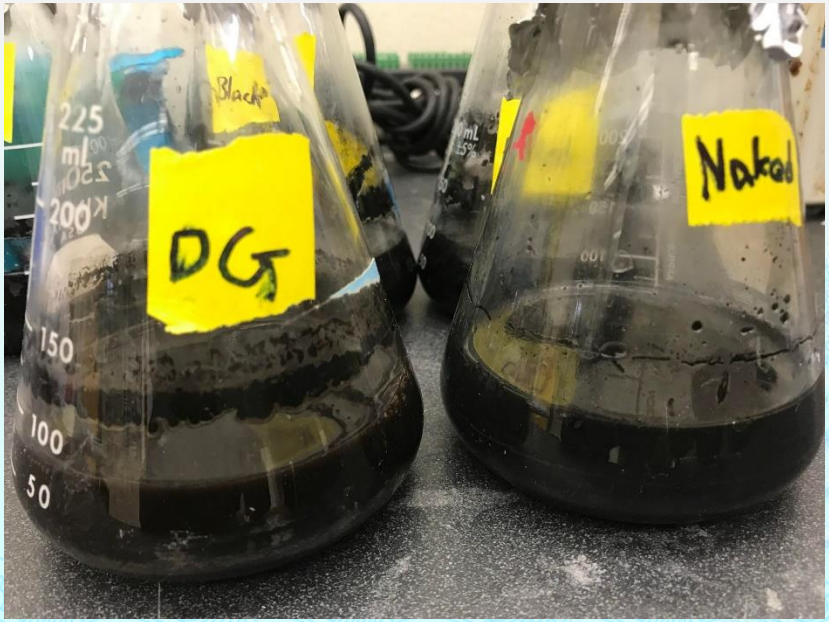
- **C33 batch test – applied dosage (5 g)**
- **Biochar – different materials**
- **Iron – different materials**
- **Biochar – applied dosage**
- **Iron – applied dosage**

Batch- Biochar screen test

Most of the biochars disintegrated……

high VM or too small size

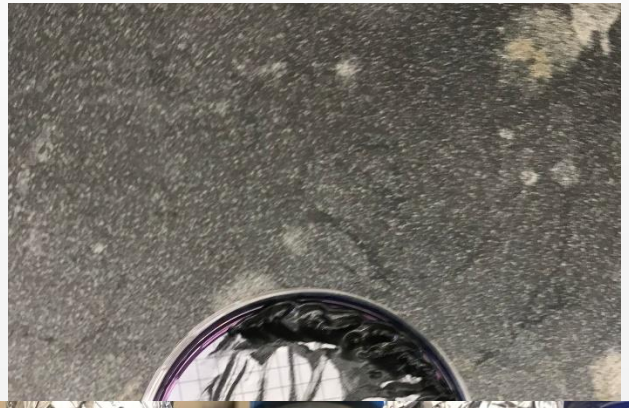
Downstream = Black water

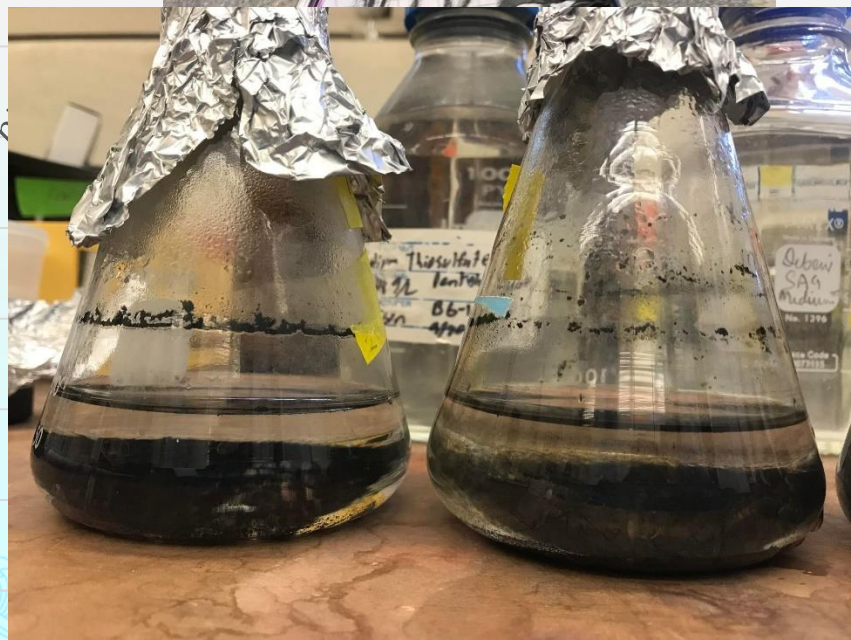


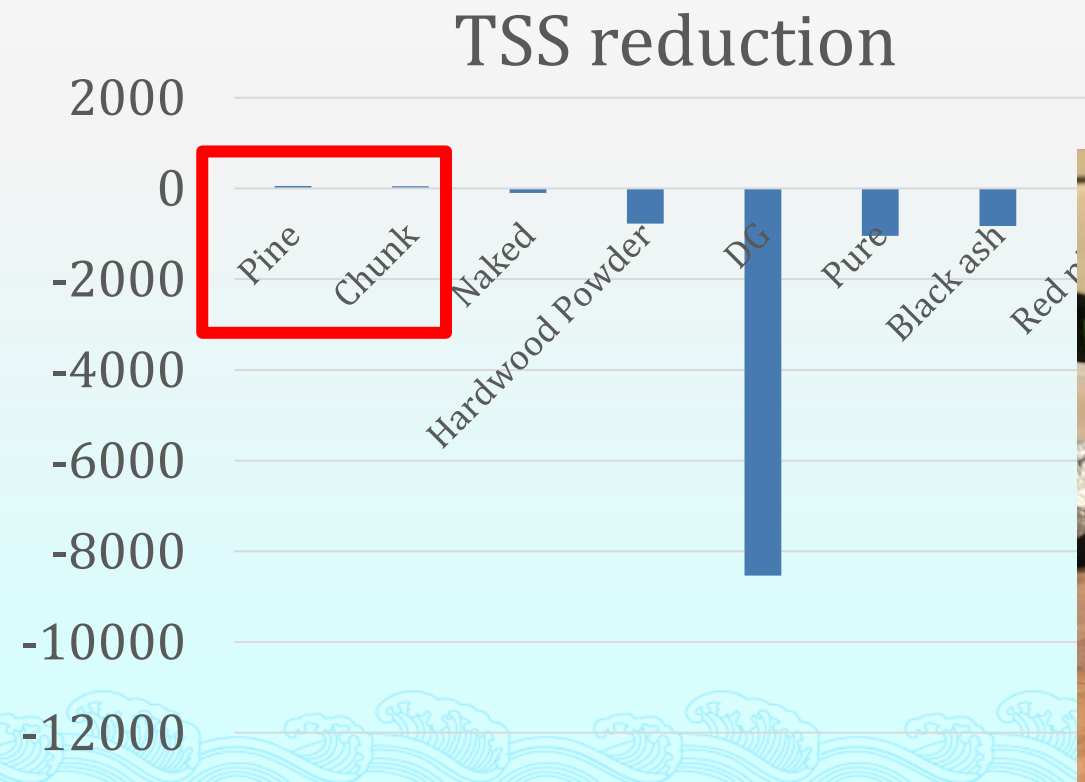
Batch- Biochar screen test

TSS is a big problem.

Pine and Chunk.





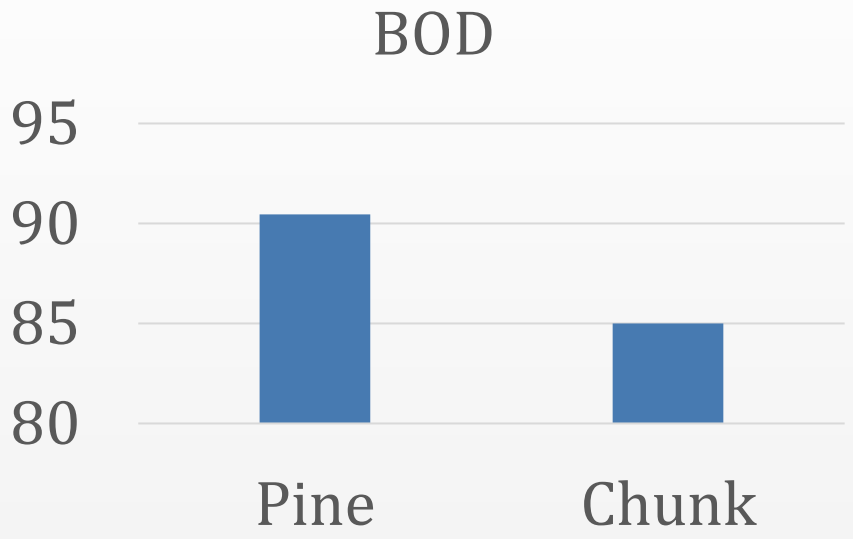


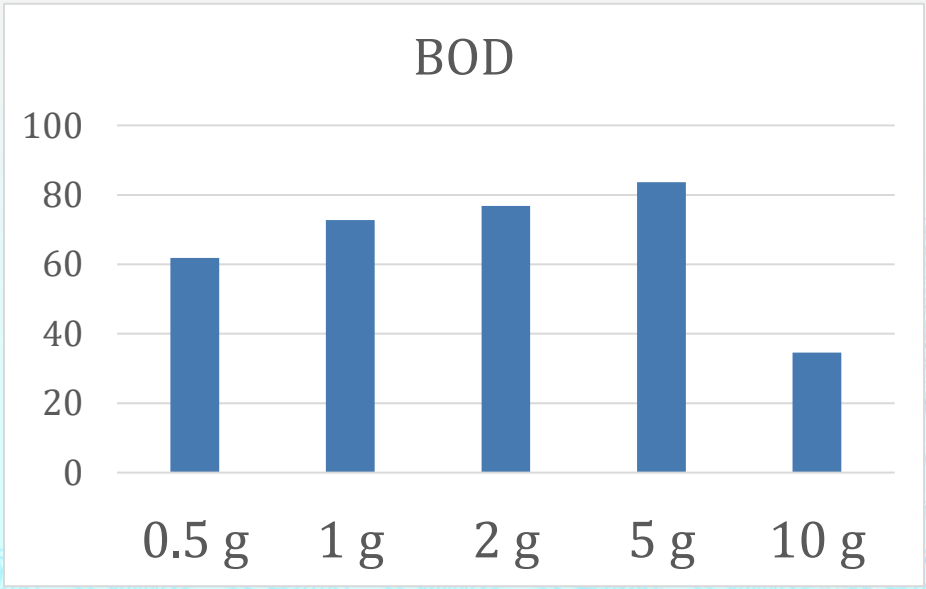
Batch- Biochar test

Biochar
Removal efficiency ↑

T-test – same dosage
p-value < 0.005 for Pine

Pine>Chunk
-Lower particle size
-Higher FC content

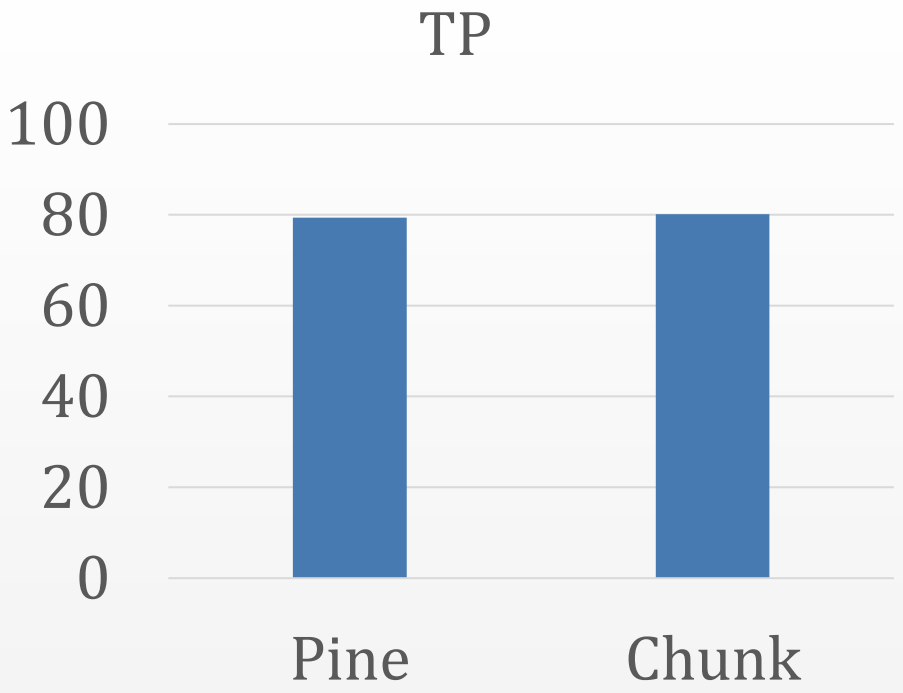


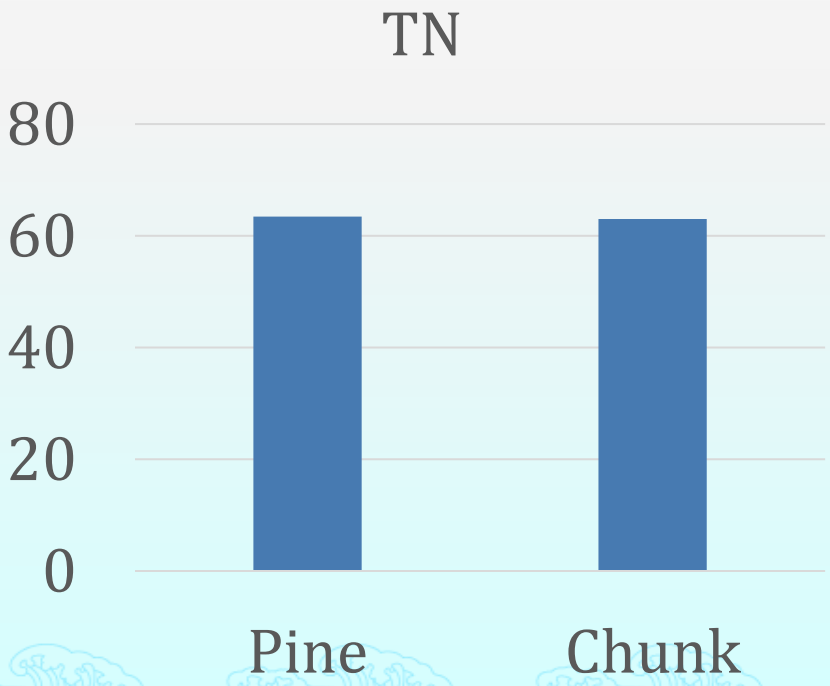


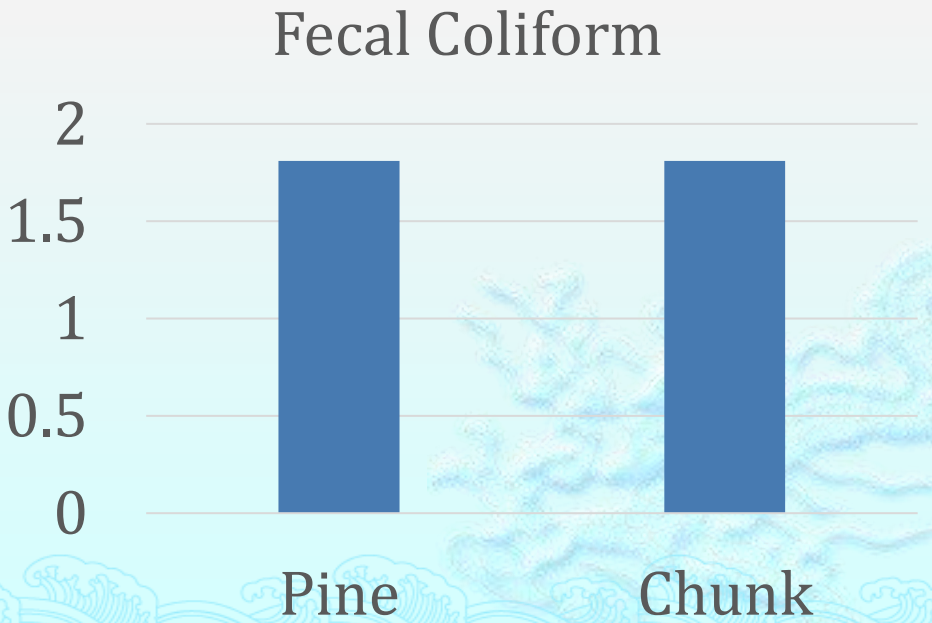
Nutrients & FC

Biochar
Removal efficiency ↑

Different biochar
→ No influence



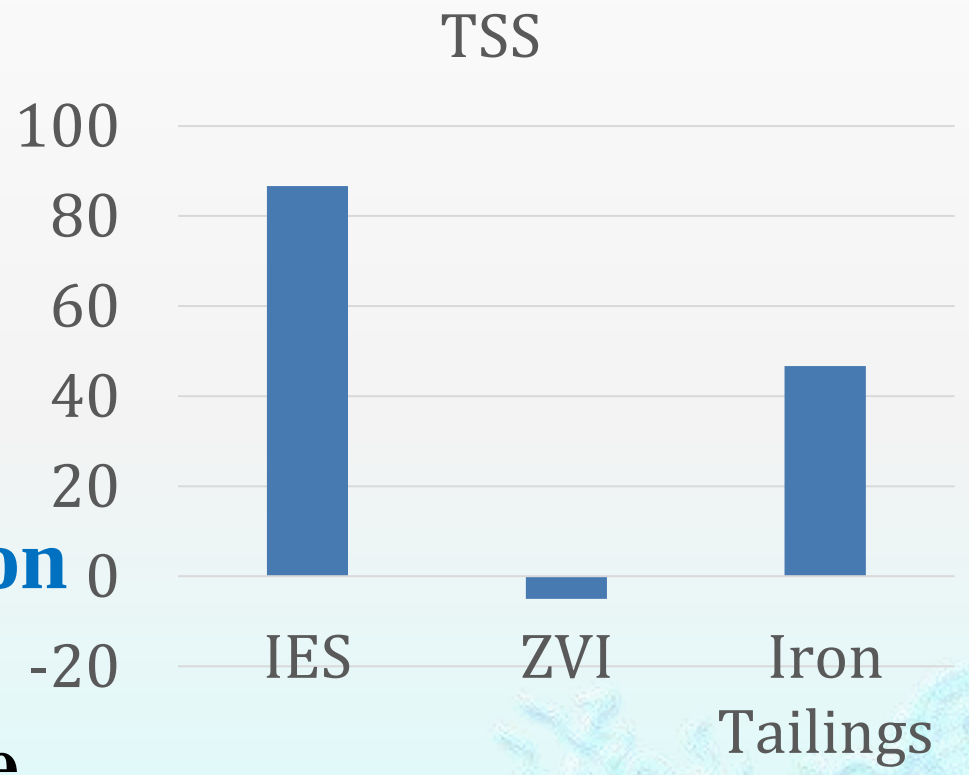




Batch tests

- **C33 batch test – applied dosage (5g)**
- **Biochar – different materials (Pine biochar)**
- **Iron – different materials**
- **Biochar – applied dosage**
- **Iron – applied dosage**

ron screen test



Red = Ferrous dissolved

Iron oxide = sedimentation

IES →best reduction rate

Iron → good adsorbent but not too much

Batch- Iron screen test

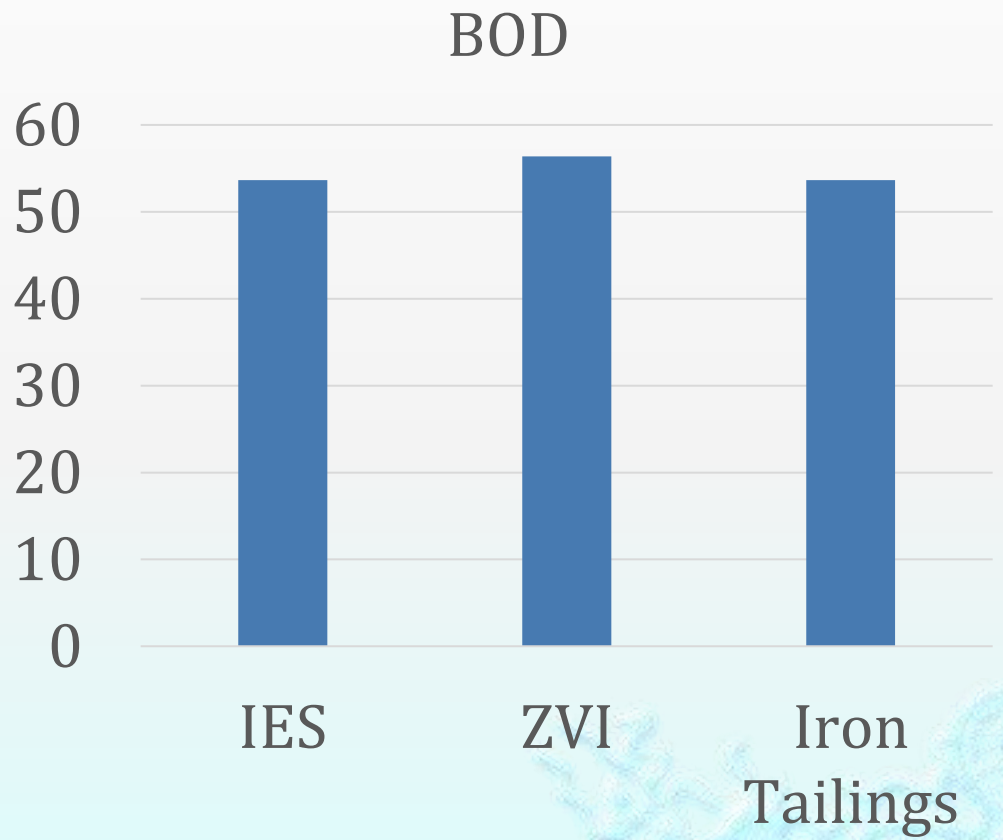
ANOVA – different iron

p-value > 0.005

Iron materials

Removal efficiency ↓

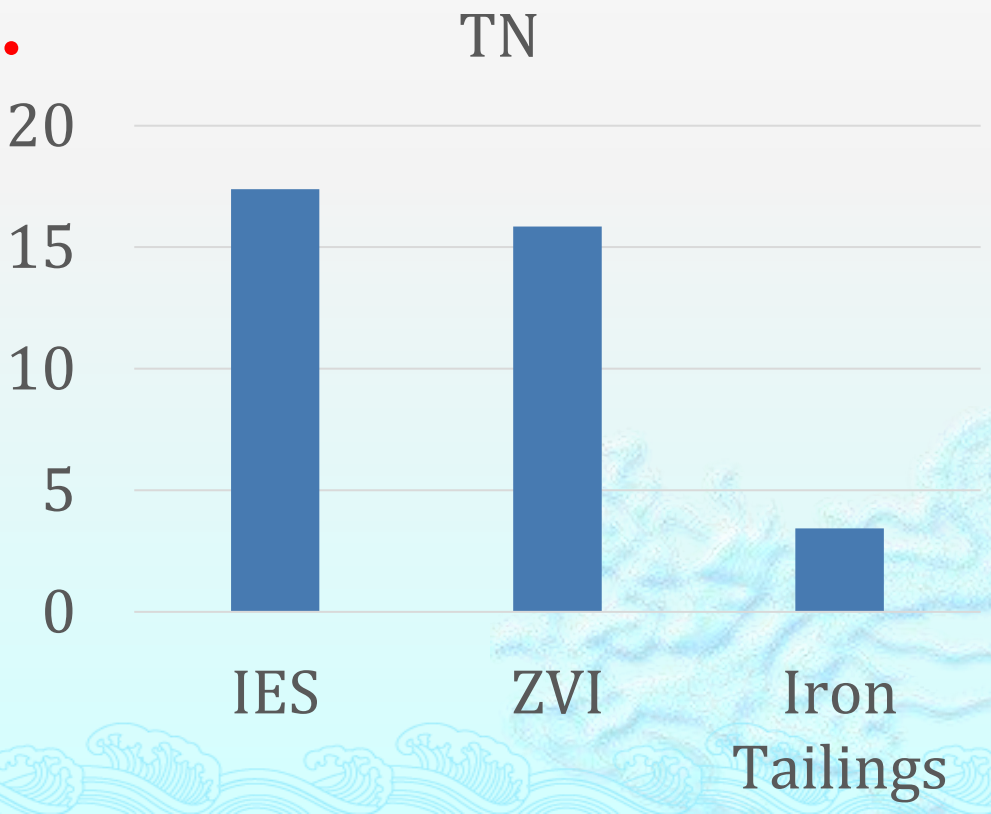
Not a perfect adsorbent for BOD.



Nitrogen!!!

Overall removal efficiency is low.

Not a perfect adsorbent for nitrogen as well.



Phosphorus

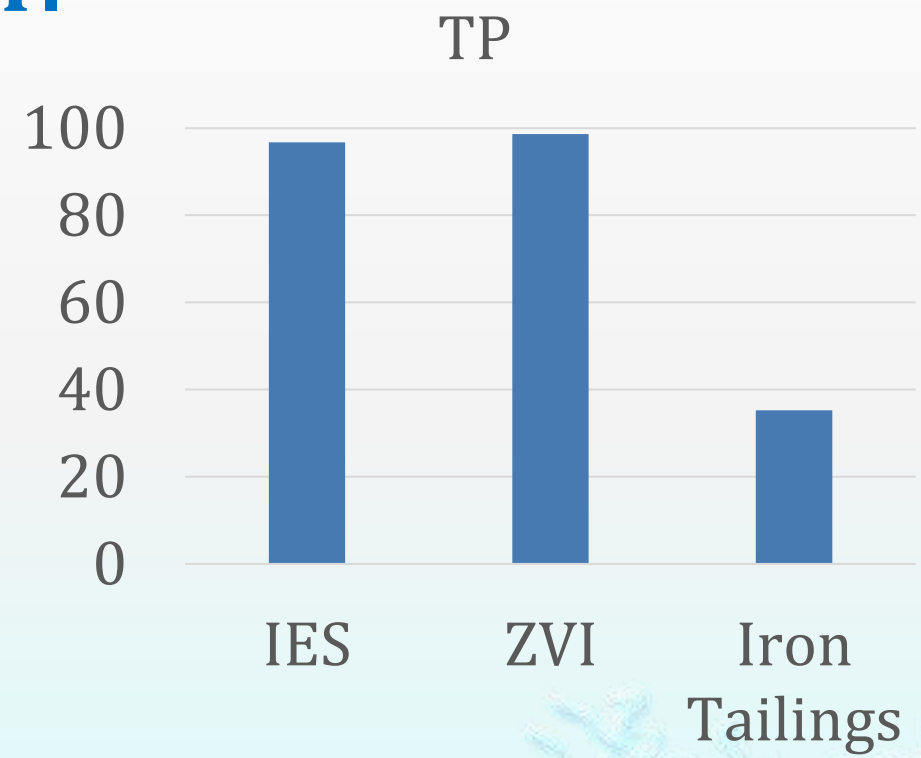
Perfect adsorbents for P.

Removal efficiency ↑

High selectivity

T-test – IES and ZVI

p-value > 0.005



Mechanism → sedimentation

$$PO_4^{3-} + Fe^{3+} \rightarrow FePO_4$$

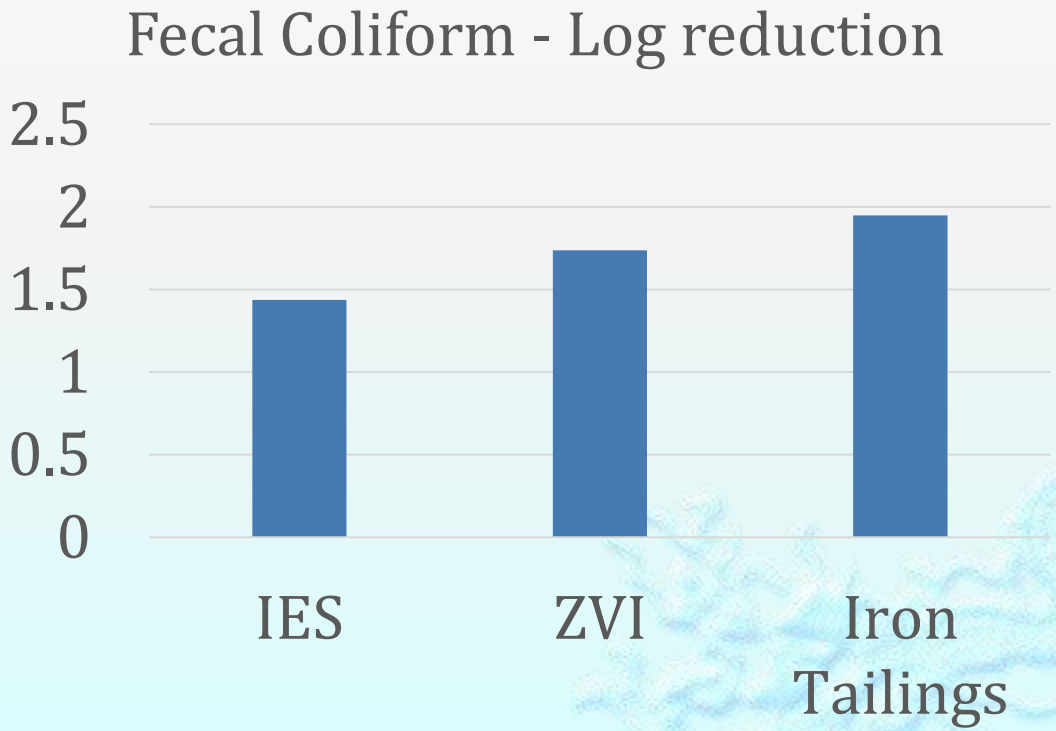
$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

$$4Fe^{3+} + PO_4^{3-} + 9H_2O \rightarrow Fe_4(OH)_9PO_4 \downarrow + 9H^+$$

Fecal Coliform

Provide higher reduction rate
1-1.3 log reduction (C33).
p-value $<$ 0.005

Different materials
p-value $>$ 0.005



Batch test

- **C33 batch test – applied dosage (5g)**
- **Biochar – different materials (Pine biochar)**
- **Iron – different materials (IES)**
- **Biochar – applied dosage**
- **Iron – applied dosage**

Batch- Pine biochar test

TSS

Lower dosage is preferred.

BOD

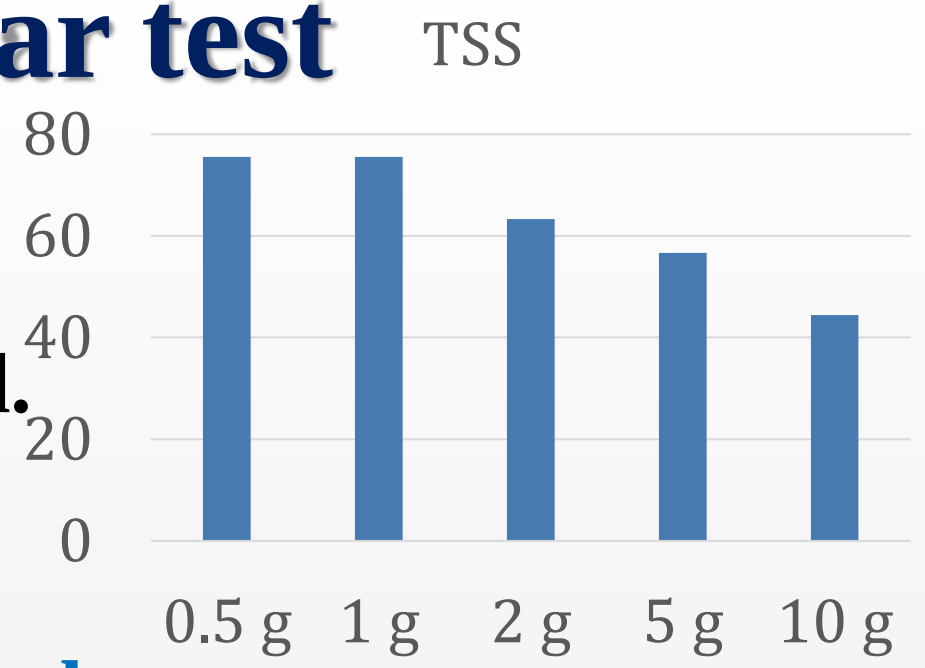
Medium dosage is preferred.

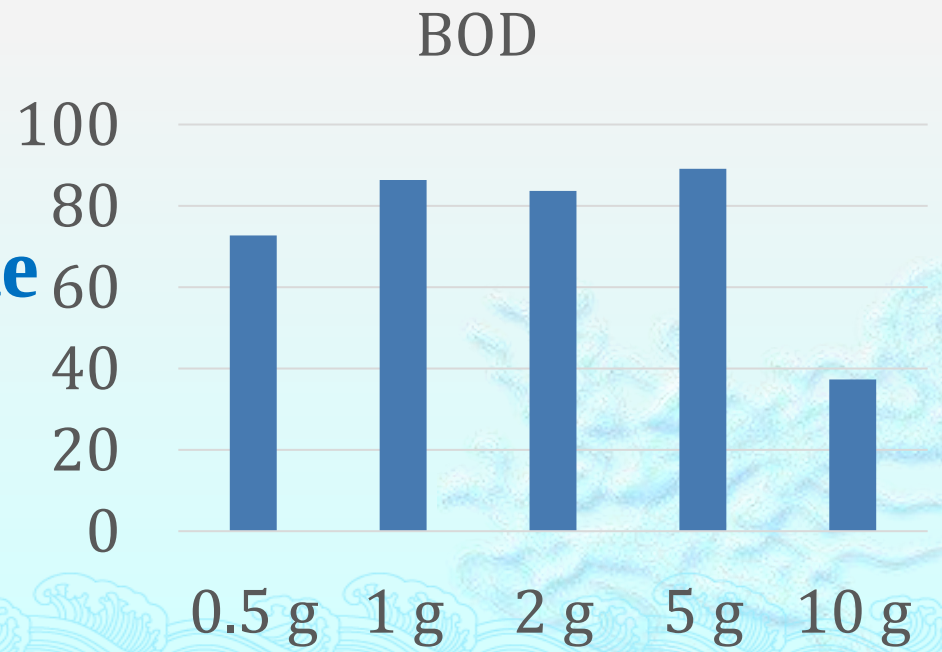
Trade-off condition

Adsorption vs disintegrate

1g, 2g, and 5g

p-value > 0.005



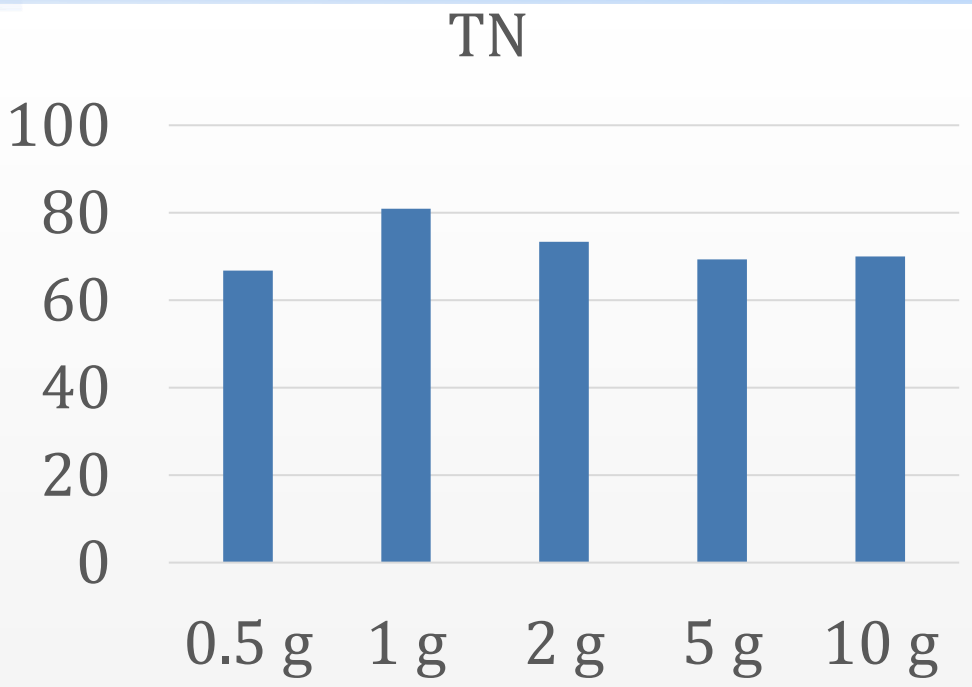


Nutrients!!!

Nitrogen

1 g dosage

80% reduction rate



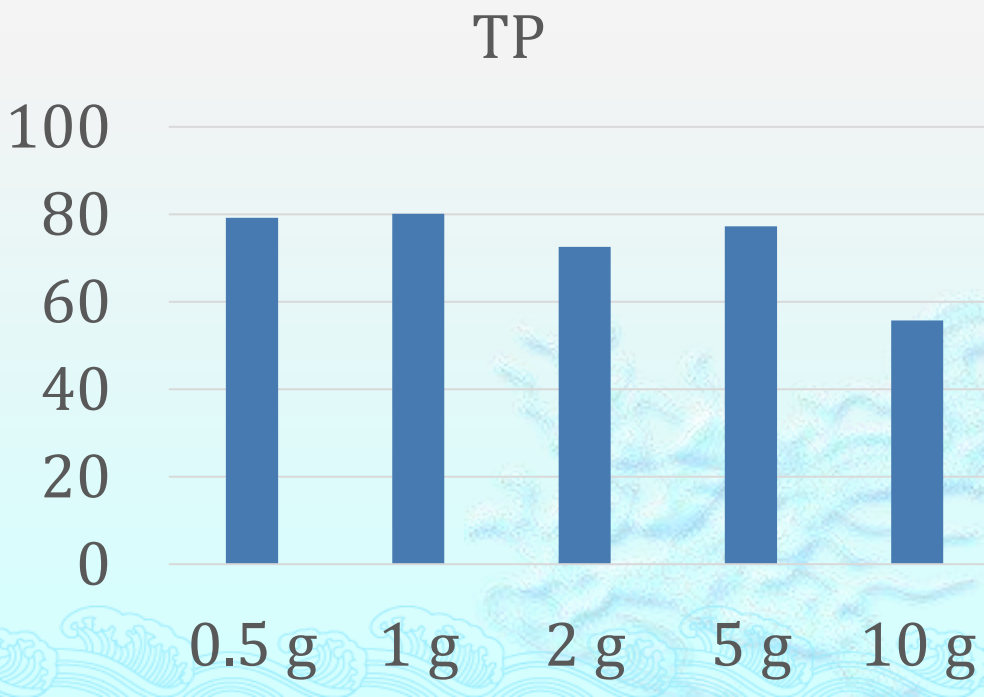
Phosphorus

~80% reduction rate
(C33 <30%)

ANOVA

No difference between

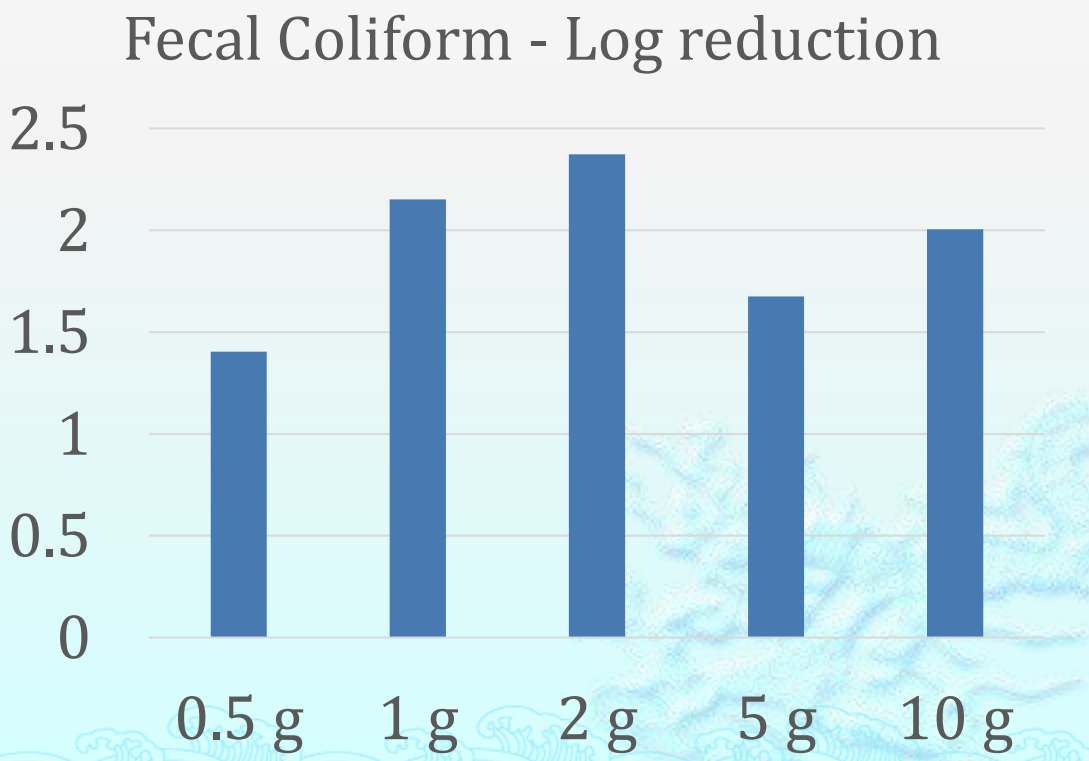
0.5, 1, 5 g



Fecal Coliform

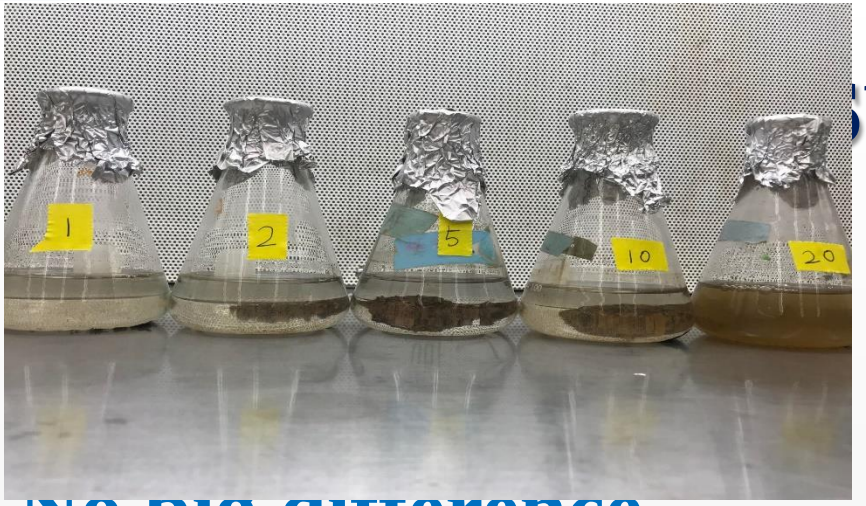
Provide higher reduction rate
1, 2, and 10 grams are able to achieve 99% removal efficiency

Different dosage
p-value > 0.005



Batch tests

- **C33 batch test – applied dosage (5g)**
- **Biochar – different materials (Pine biochar)**
- **Iron – different materials (IES)**
- **Biochar – applied dosage (1g)**
- **Iron – applied dosage**



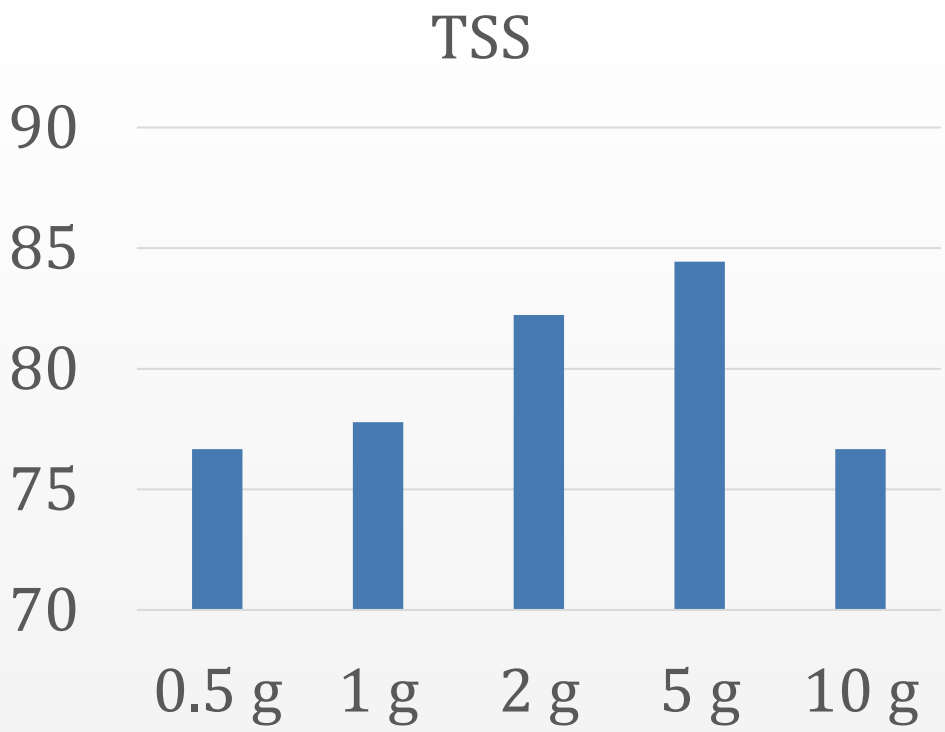
No big difference

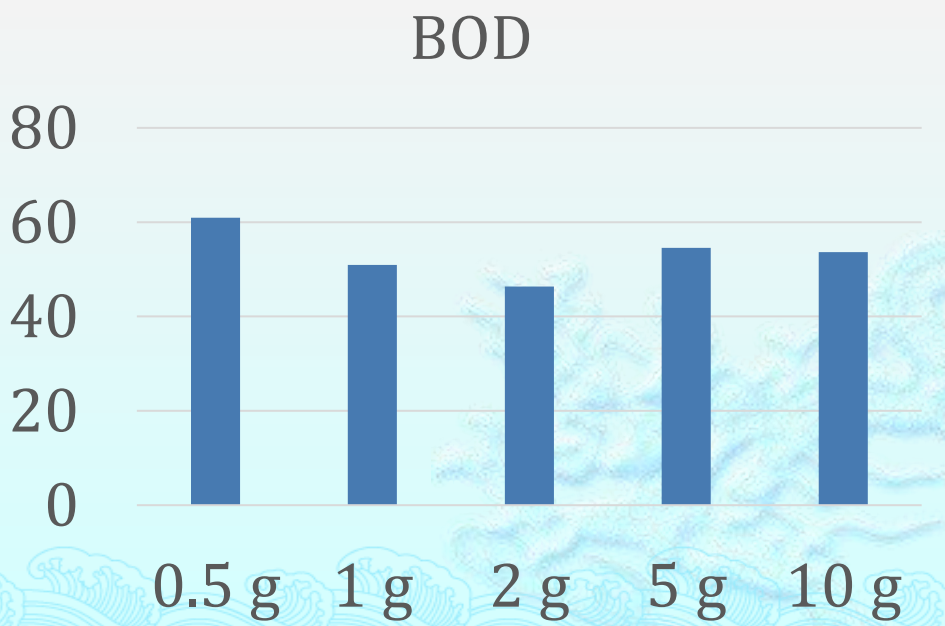
BOD

Didn’t vary much

Trade-off condition

Adsorption vs Iron oxide





Nutrient!!!

High selectivity

Perfect adsorbents for P.

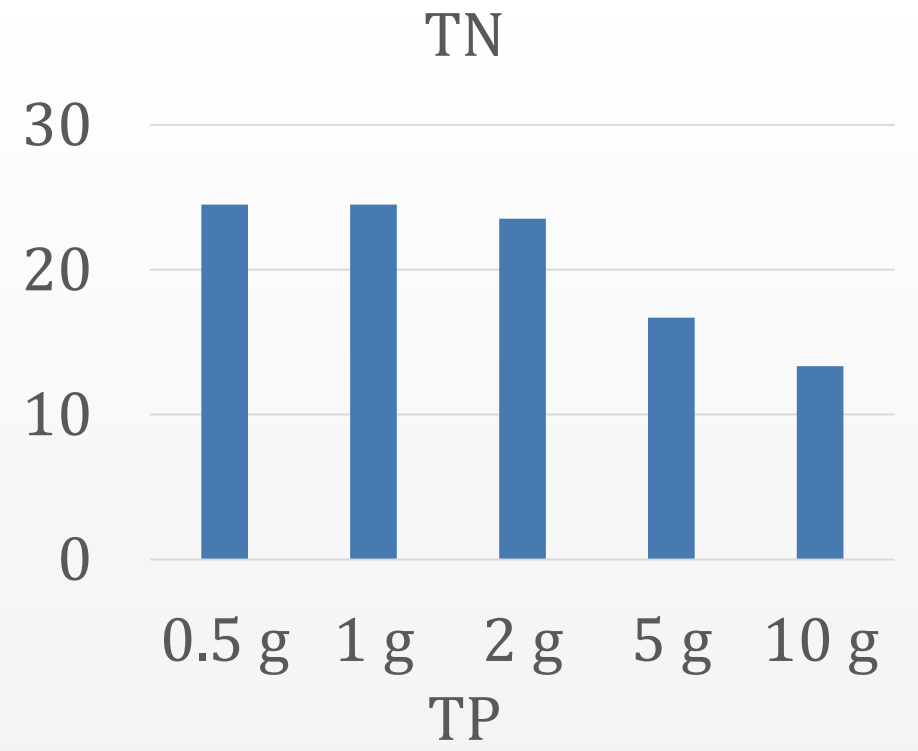
Removal efficiency of N is low.

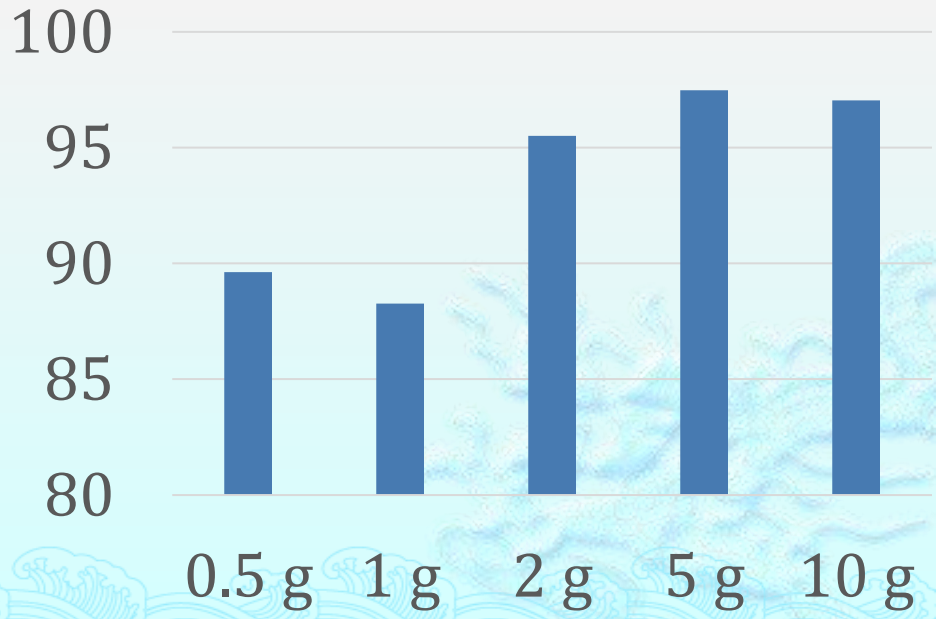
TP

High dosage is preferred

2g, 5g, and 10g

p-value > 0.005

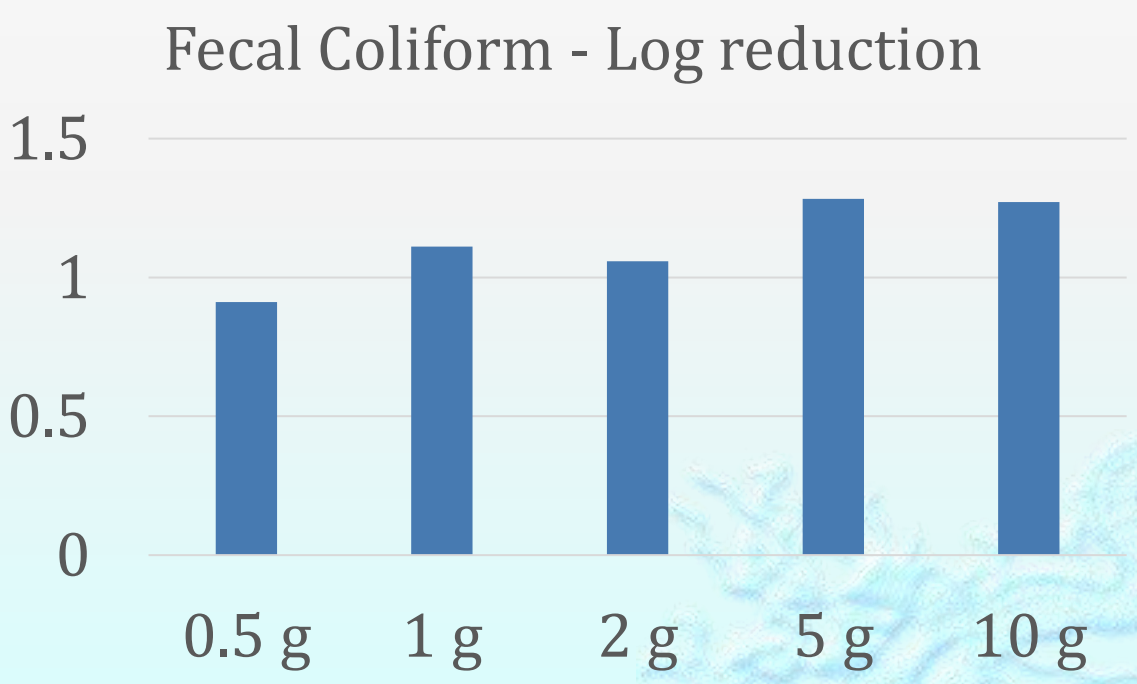




Fecal Coliform

No difference between C33 and IES

Different dosage
p-value > 0.005



Batch test

- **C33 batch test – applied dosage (5g)**
- **Biochar – different materials (Pine biochar)**
- **Iron – different materials (IES)**
- **Biochar – applied dosage (1g)**
- **Iron – applied dosage (2g)**

Best materials comparison

C33 sand (removal efficiency, %)

BOD	TSS	TP	TN	Bacteria
83.64	66.67	21.33	57.44	90.85

Pine (removal efficiency, %)

BOD	TSS	TP	TN	Bacteria
86.36	75.55	80.15	80.94	99.30

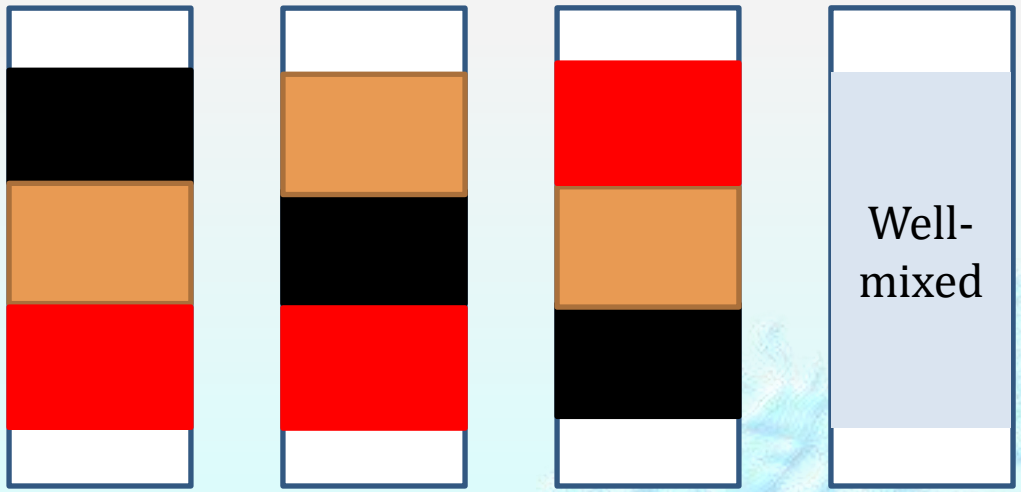
IES (removal efficiency, %)

BOD	TSS	TP	TN	Bacteria
46.36	82.22	95.51	23.53	91.27

Best material with the best applied dosage

Future work - Column test

- Hydraulic Loading rate – 1.2 gallons/sq ft/day
- Intermittent operation
  - 3 to 7 L/min (0.8-1.85 gallons/min)
  - 8 to 15 times/day
  - Morning:30%, Noon:10%, and Night:60%
- Mixture configuration



- Durability – breakthrough and clog

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- **Connelly-GPM**

Managing Septic System Contaminants

Primary Investigator: Sara Heger
Co-Investigators: NA
Industry Partners: Stantec
Award Type: Seed Grant - Postdoctoral Research Scholar (with NRRI Travel Grant)

Problem: There are over 600,000 subsurface sewage treatment systems (SSTS) processing over 40 billion gallons of wastewater per year in Minnesota. Even with proper siting and design there is the potential for nutrients to reach surface or groundwater particularly with commercial and cluster scale SSTS where regulations and risk increase in relation to nutrient removal in sensitive environments. Biochar and iron-enhanced sand (IES) have been found to be effective in treating stormwater but their performance for the treatment of wastewater from septic systems is poorly understood.

Solution: This project will test several types of biochar and IES's effectiveness at removing contaminants from wastewater in the laboratory (1) with absorption testing, and (2) in enhanced soil columns to evaluate its potential to improve SSTS treatment.

Impact: The intended outcomes of this study are the development of a new sustainable technology for removal of dissolved contaminants from septic system wastewater. This work could open a new client base for biochar and IES across Minnesota. These outcomes will lead to mitigation of water pollution and jobs creation, topics that are vital to the health and well-being of Minnesota residents.

Thank you for your listening!

Question?

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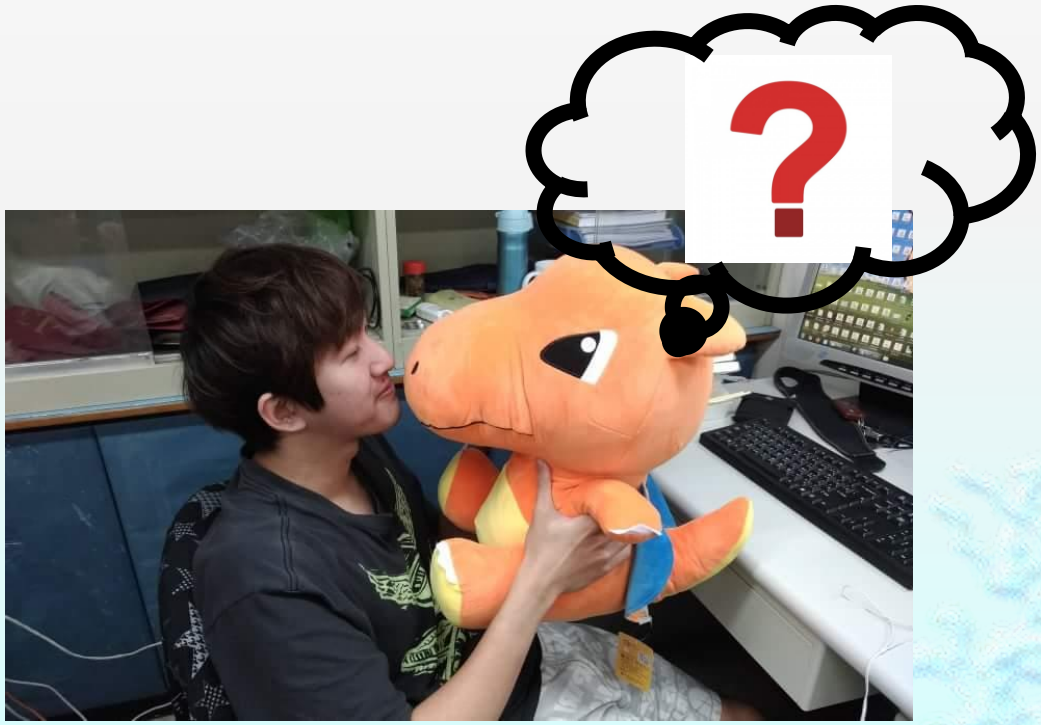

Price

- C33 concrete sand
- 1 cubic yard – 16.82
- **Less than a cent per pound**

- ZVI
- $20 to $77 per pound depending on the quantity

- **IES – 1-4 per pound**

- Pine Biochar
- $58 per 23 pound
- **2.5 per pound**

C33 vs Biochar

C33 sand (removal efficiency, %)

BOD	TSS	TKN	TN	TP/PO_4	Bacteria
83.64	66.67	69.76	57.44	21.33/60.17	90.85

Pine (removal efficiency, %)

BOD	TSS	TKN	TN	TP/PO_4	Bacteria
90.45	56.67	95.62	63.44	79.35/79.62	98.45

Chuck (removal efficiency, %)

BOD	TSS	TKN	TN	TP/PO_4	Bacteria
85	46.67	73.39	63.01	80.15/78.29	98.45

Evaluate under the same basis – 5 g/50 ml

Iron materials comparison

IES (removal efficiency, %)

BOD	TSS	TKN	TN	TP/PO_4	Bacteria
53.64	86.67	20.85	17.39	96.76/98.78	96.34

ZVI (removal efficiency, %)

BOD	TSS	TKN	TN	TP/PO_4	Bacteria
56.36	-5.00	15.28	15.85	98.66/99.58	98.17

Iron tailings (removal efficiency, %)

BOD	TSS	TKN	TN	TP/PO_4	Bacteria
53.64	46.67	20.65	3.43	35.20/67.35	98.87

Evaluate under the same basis – 5 g/50 ml