Pollutant Removal Using Vetiver Grass and Generation of Biofuel and Biochar From Spent Biomass: A Circular Economy Model

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Problems caused by stormwater runoff

Visible threat:

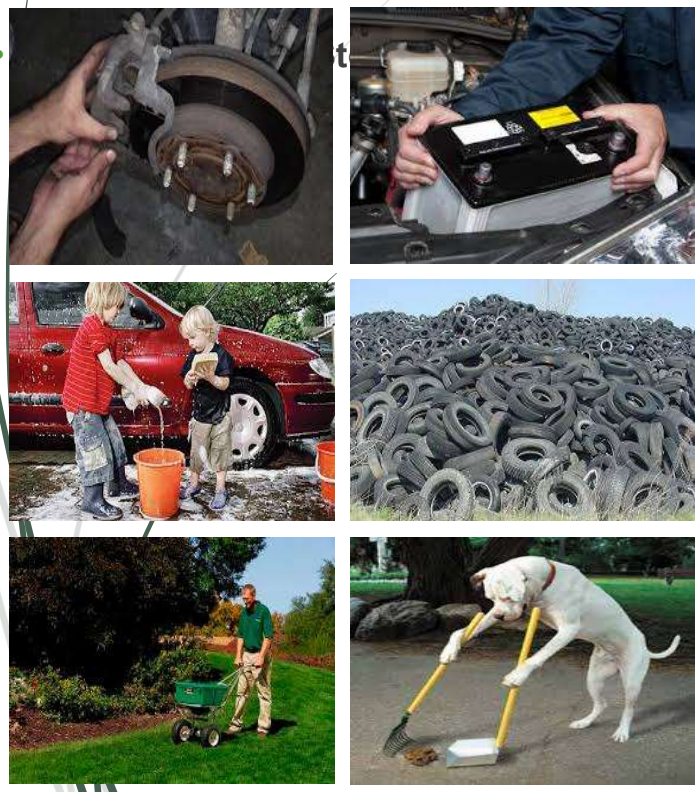
- Water ponding and flooding

Invisible threat:

- Stormwater pollution

Source: https://twitter.com/jgodynick/status/1044673777341214722
https://patch.com/new-jersey/secaucus/dramatic-photos-secaucus-flooding-tuesday

Problems caused by stormwater runoff



- Metals
- Nutrients
- Total suspended solids

Source: https://sigearth.com/stormwater-runoff-a-top-cause-of-water-pollution/

Problems caused by stormwater runoff

Invisible threat: Stormwater pollution

Visible threat:

- Water ponding and flooding

Invisible threat:

- Stormwater pollution

Adverse environmental impacts

- Affecting reproduction rates and life spans of aquatic species
- Disrupting food chains in aquatic systems
- Affecting water supplies
- Eutrophication

Source: https://www.draper.ut.us/1021/Pollution-Information
https://www.stevens.edu/news/how-stevens-helping-save-oceans-and-lakes-trimming-nutrient-runoff

Vetiver (*Chrysopogon zizanioides*)

Floating treatment platform (FTP)

- High tolerance to harsh climatic conditions
- High biomass
- Massive root system
- Can grow hydroponically
- High capability of nutrient and metal uptake

Parameter		Range of tolerance
pH		3.3-12.5
Temperature	Frost	5°F (-15°C)
	Heat	140°F (+60°C)
Drought		15 months
Altitude		2800 m

Source: http://vetiver.com.vn/vetiver-grass-system/

Objective

To develop a low-cost, efficient, “green” retrofit for stormwater retention ponds to enhance their metal and nutrient removal capacity and to use spent vetiver as feedstock for the generation of bioethanol and biochar to form a circular economy model.

Experimental design

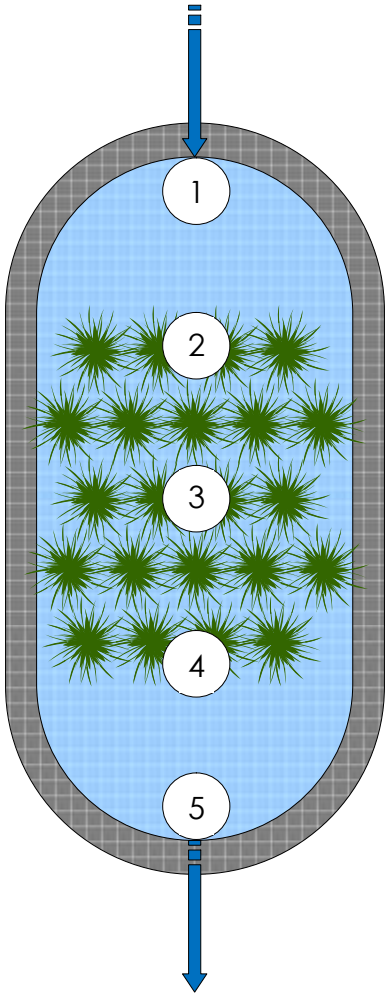
- **Reactor**: 150-gallon tanks
- **Permanent pool volume**:
  100 gallons
- **Simulation volume**:
  33 gallons over 2 hours
- **Spiked initial concentrations**:
  50 µg/L Cu
  200 µg/L Pb
  180 µg/L Zn
  900 µg/L P
  5.5 mg/L NO_3^-.
- **Monitoring period:**
  28 days for each simulation, 3 simulations in total

Two non-vegetated FTPs (control)

Two vegetated FTPs (vetiver)

30 mins → 60 mins → 90 mins → 120 mins → 1 day → 2 days → 3 days → 6 days → 9 days → 12 days → 15 days → 18 days → 21 days → 24 days → 28 days

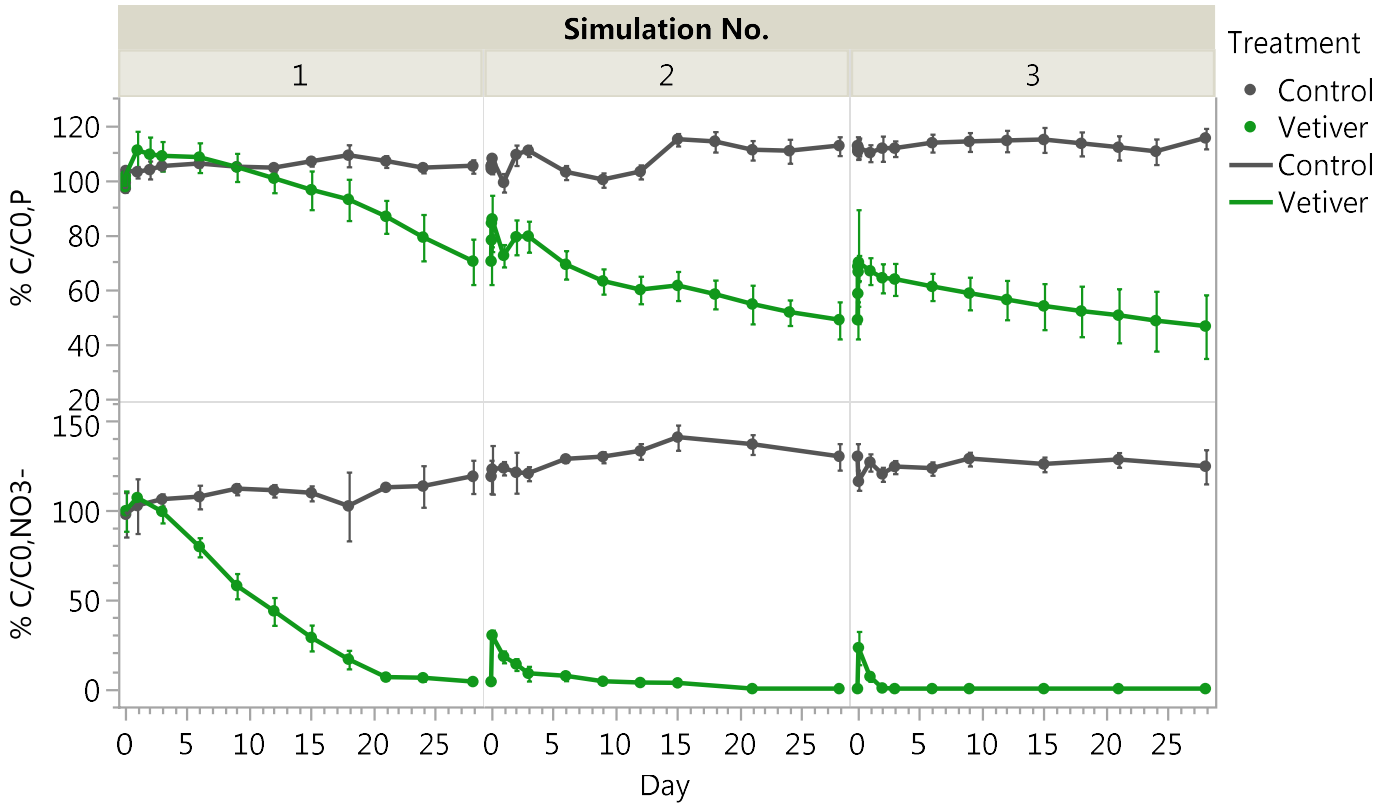
Experimental design



Results – Pollutant Removal

P

NO_3^-

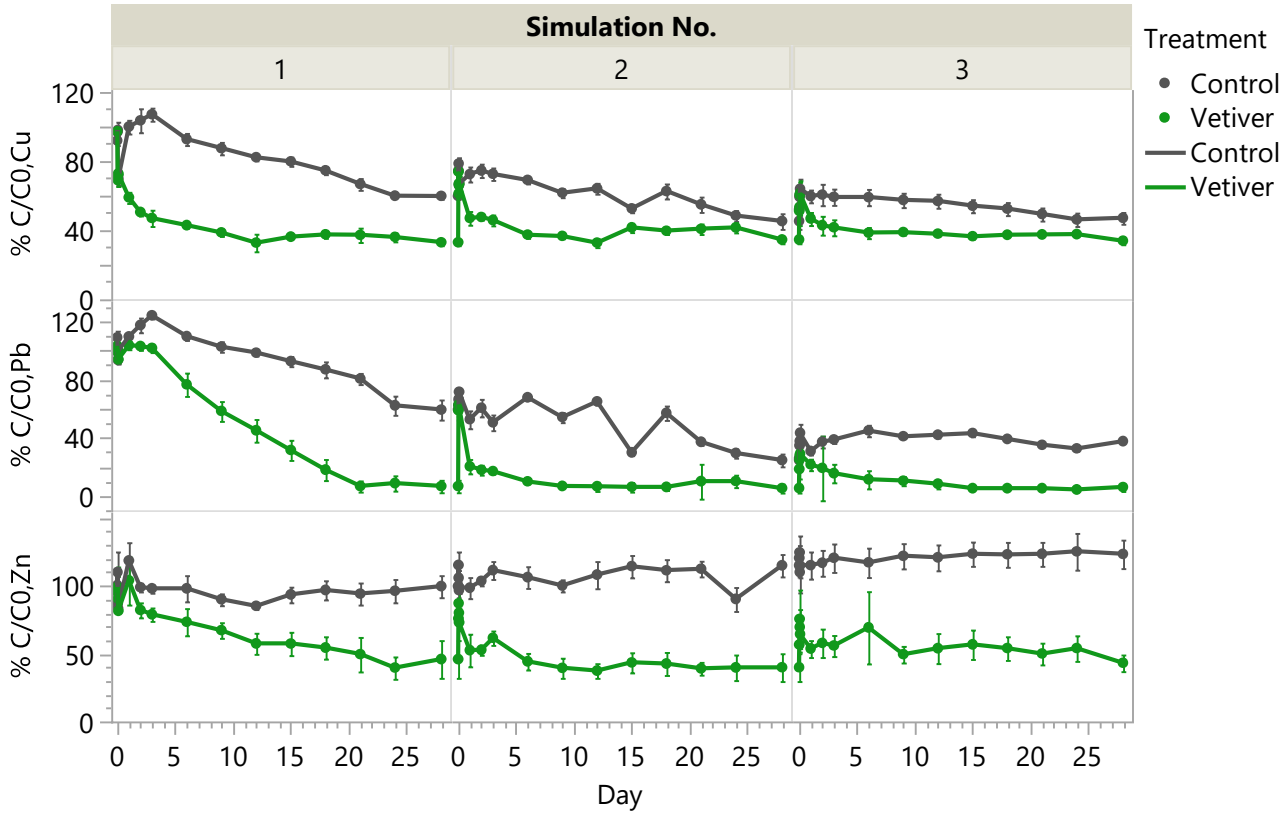


Results – Pollutant Removal

Cu

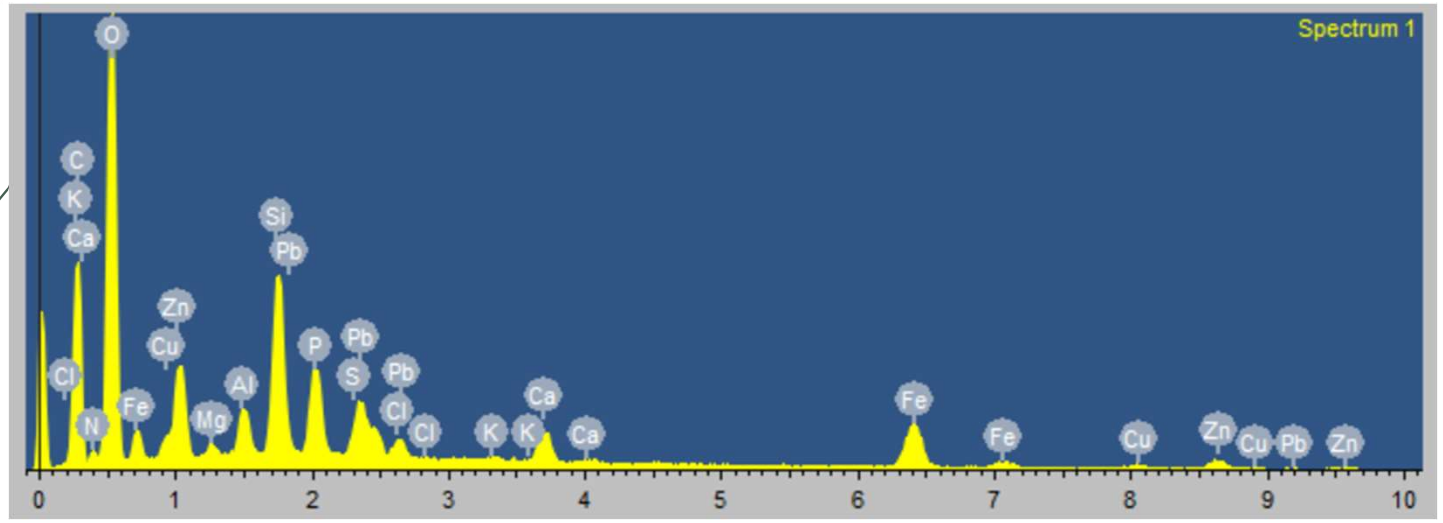
Pb

Zn

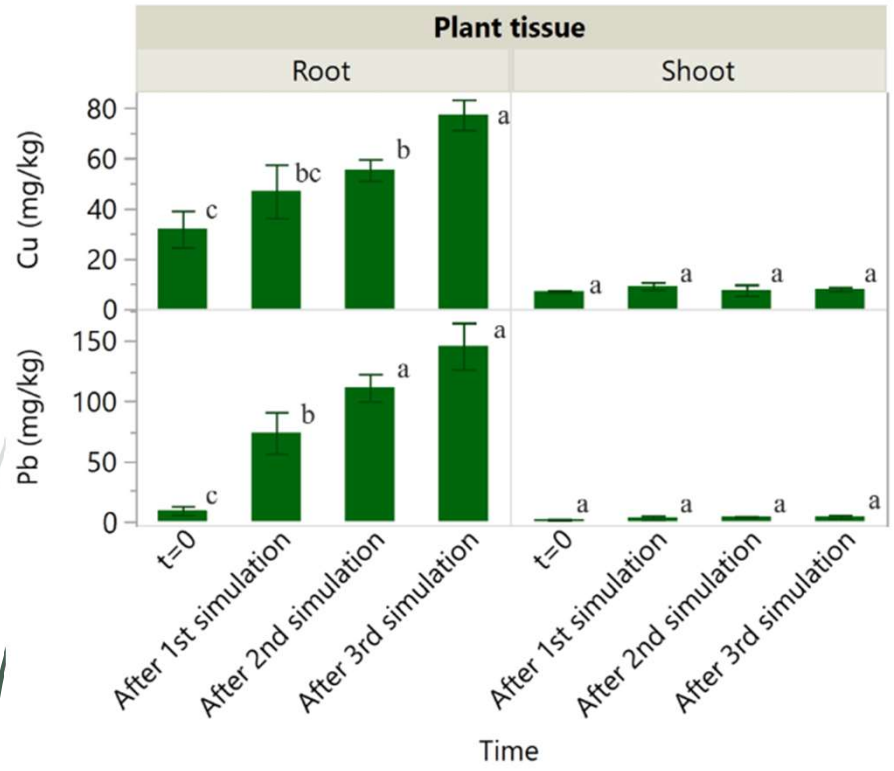


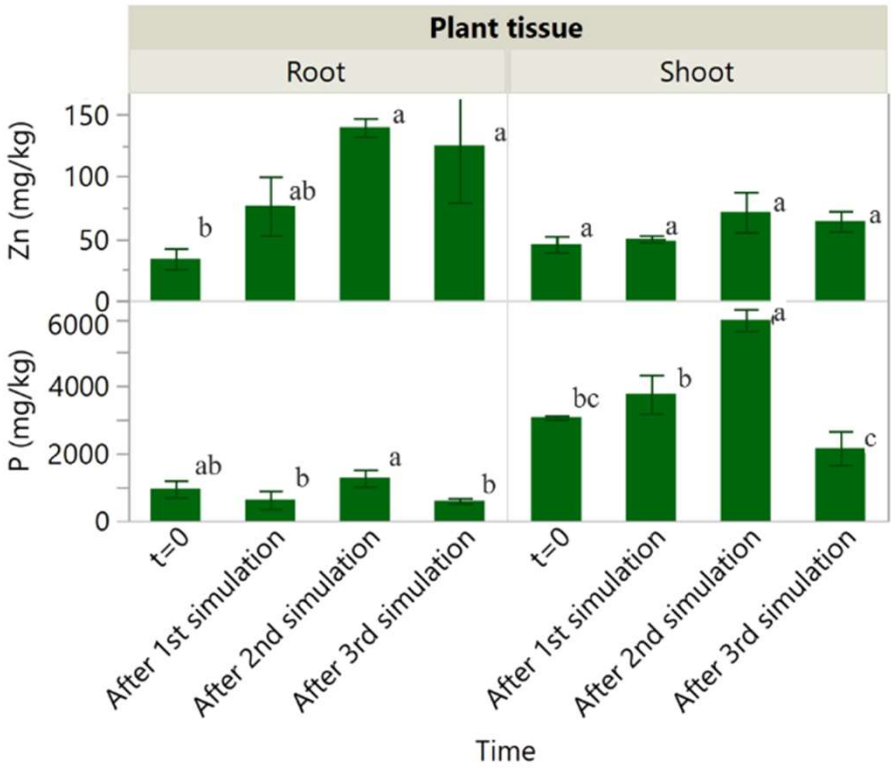
Results – Pollutant Removal

EDS spectrum of the sediment

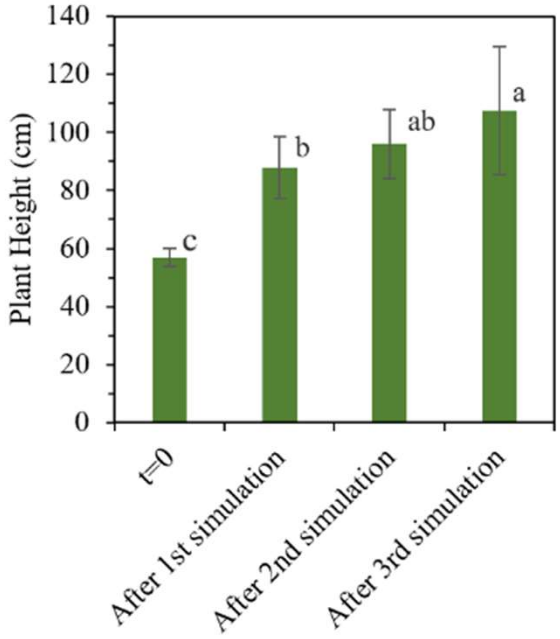


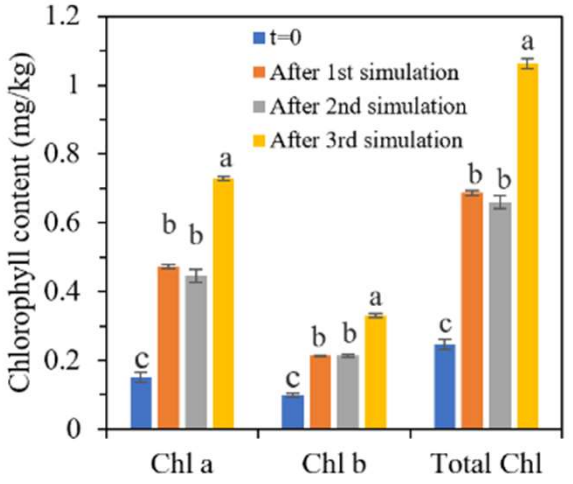
Results – Pollutant Distribution in Vetiver



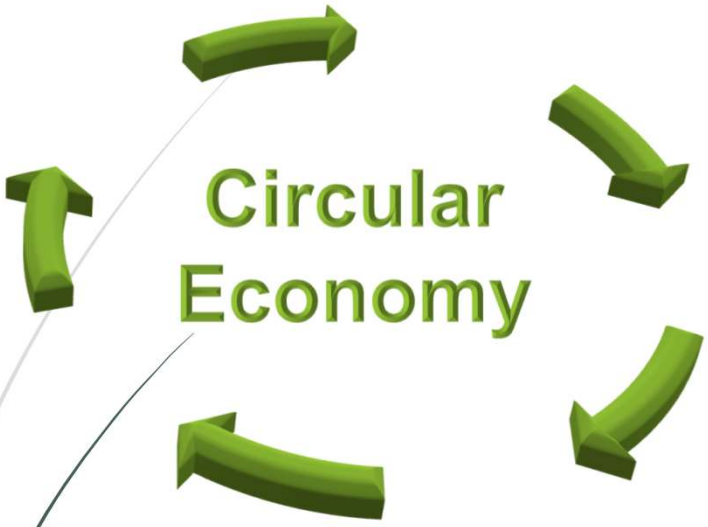


Results – Plant growth and chlorophyll content





Results – Physicochemical characteristics of vetiver biochar



Biochar production:

The roots of the spent vetiver were washed clean, air dried, and ground before pyrolysis at 500℃ held for 60 mins.

Parameter	Value
Yield	51.28%
BET Surface Area	171.6 m^2/g
pH	9.78 ± 0.13
Electric Conductivity	184.5 ± 21.3 µS/cm
Ash Content	23.6%
Cation Exchange Capacity	98 cmol/kg
Bulk Density	0.57 gm/ml
C	69.87 %
H	2.824 %
O	1.720 %
N	19.37 %
H/C	0.04
O/C	0.025
N/C	0.28
Liming Value	3.06 % $CaCO_3$

Results – Physicochemical characteristics of vetiver bioethanol

Bioethanol production:

The bioethanol was generated from the shoots of the spent vetiver via multiple steps, including

1) preparation of biomass,
2) dilute acid-alkali pretreatment,
3) enzymatic hydrolysis,
4) bioethanol fermentation, and
5) distillation.

Parameter	Test method	Value
Cellulose	Yang et al., 2006	32.86 %
Hemicellulose	Yang et al., 2006	34.03 %
Lignin	Yang et al., 2006	14.69 %
Extractives	Yang et al., 2006	9.87 %
Bioethanol Yield	Zabed et al., 2016	16.58 g/L (236.89 mg/g)
Ethanol Content	ASTM D 5501	98.86 %
Density at 25°C	ASTM D 4052	0.77 g/mL
Calorific Value	ASTM D 2014-96	31.36 MJ/kg
Viscosity	ASTM D 88-94	1.02 cSt
Sulfur content	ASTM D 3177-89	0.03 wt %
Water content	ASTM D 95-70	1.01 %
Research Octane Number	ASTM D 2699	107

Yang, H., Yan, R., Chen, H., Zheng, C., Lee, D.H., Liang, D.T., 2006. In-depth investigation of biomass pyrolysis based on three major components: hemicellulose, cellulose and lignin. Energy & Fuels 20, 388–393.
Zabed, H., Sahu, J.N., Boyce, A.N., Faruq, G., 2016. Fuel ethanol production from lignocellulosic biomass: an overview on feedstocks and technological approaches. Renew. Sustain. energy Rev. 66, 751–774.

Results – Potential metal residues in biochar and bioethanol

Metal leaching potential from biochar:

- Synthetic precipitation leaching procedure (SPLP) (USEPA, 1994)
- Toxicity characteristic leaching procedure (TCLP) (USEPA, 1992)

	SPLP				TCLP			
	Biochar	Spent Shoot	Spent Root	Regulatory Level [a]	Biochar	Spent Shoot	Spent Root	Regulatory Level [b]
Ag	BDL	BDL	BDL	800	BDL	BDL	BDL	5000
As	BDL	BDL	BDL	3	BDL	BDL	BDL	5000
Ba	297.53	261.15	397.82	120000	422.12	512.78	282.31	100000
Cd	BDL	BDL	BDL	80	BDL	8.25	BDL	1000
Cr	BDL	BDL	BDL	NR [c]	2.75	4.56	3.02	5000
Pb	2.29	7.56	4.83	100	9.24	17.18	8.31	5000
Hg	BDL	BDL	BDL	40	BDL	BDL	BDL	200
Se	BDL	BDL	BDL	800	BDL	BDL	BDL	1000

BDL: Below detection limit

[a] SPLP criterion: Higher of the health-based leachate criterion or aqueous practical quantitation levels (NJDEP, 2013)

[b] TCLP criterion: maximum concentrations of contaminants for the toxic characteristics from Title 40 CFR 261.24 - Toxicity characteristic

[c] NR: Not regulated

Metal contents in bioethanol:

- No metals were found in bioethanol.

USEPA, 1994. Method 1312: Synthetic precipitation leaching procedure
USEPA, 1992. Method 1311: Toxicity characteristic leaching procedure
NJDEP, 2013. Development of site-specific impact to ground water soil remediation standards using the synthetic precipitation leaching procedure.

Summary

- Floating treatment platform with vetiver is an effective retrofit for stormwater retention ponds to remove nutrients and metals.
- The majority of P was translocated from the below-ground tissues to the above-ground tissues, while the majority of the removed metals (Cu, Pb, and Zn) were localized in the vetiver root.
- No visible plant stress symptoms was observed.
- The yield and quality of biochar and bioethanol generated from the spent vetiver biomass were desirable.

Thank you !

Acknowledgement:

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