Water treatment potential of crop-waste biochar: an investigation for the developing world

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Abstract

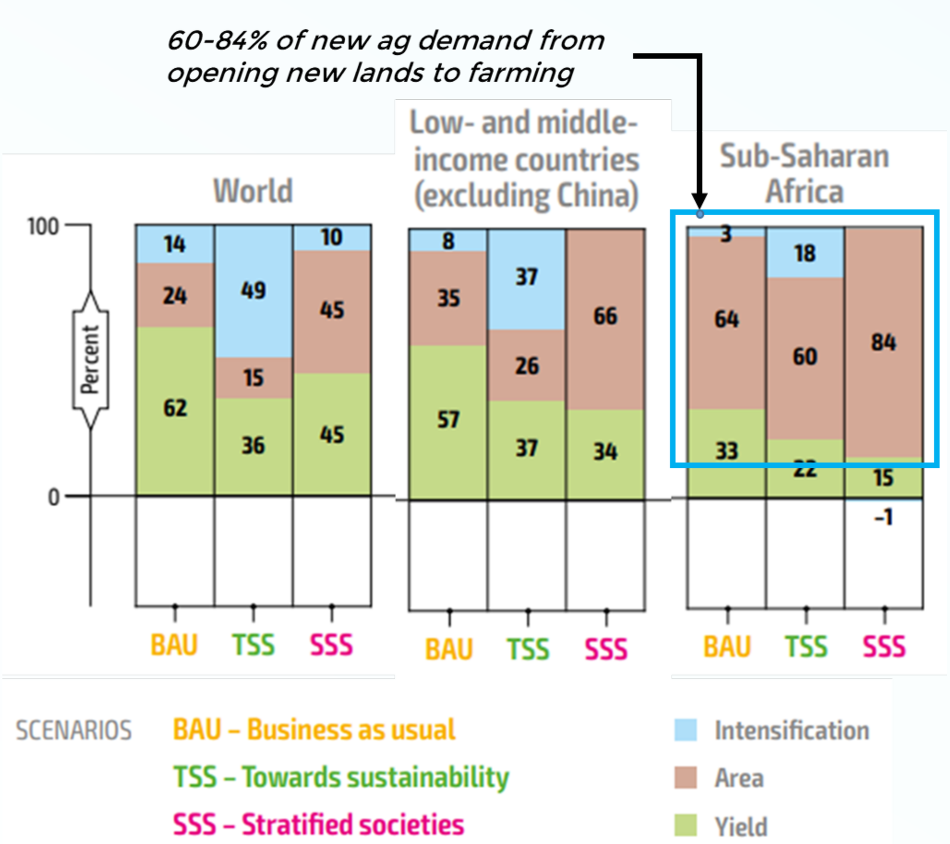
The developing world has a high need for water treatment generally, and this is especially true for agricultural water. In addition to limited access to funds, technology, and expertise future decades will see an increase in conversion of virgin land to arable land. Agricultural runoff will have environmental impacts. The creation of biochar from crop residue can be optimized for many environmental uses. In our study, we made biochar from several types of residues and in multiple ways. We examined its adsorption potential using common dyes. The potential for easy-to-produce, inexpensive biochar is demonstrated by the results.

Motivation

Pressures in developing world farming (UNFAO 2017)

- World population 10 billion by 2050; additional agricultural demand (food, fiber, fuel) will be ***50% more than 2017.***
- Currently, 800 million people chronically hungry and 2 billion suffer micronutrient deficiency.
- Sub-Saharan African population will be **650 million in 2050 and 1.8 billion in 2100** (5-6x today's population).

How ag demand will be met in 2050 (UNFAO 2018)



Agricultural runoff remains an environmental and economic challenge

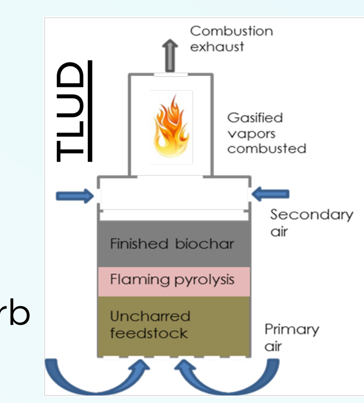
Eight major pollutants classes for different types of agriculture (Mateo-Sagasta, UNFAO 2017)

Type	Relative contribution		
	Crop	Livestock	Aquaculture
Nutrients	***	***	*
Pesticides	***	-	-
Salts	***	*	*
Sediment	***	***	*
Organic matter	*	***	**
Pathogens	*	***	*
Metals	*	*	*
Emerging pollutants	-	***	**

Objectives & methods

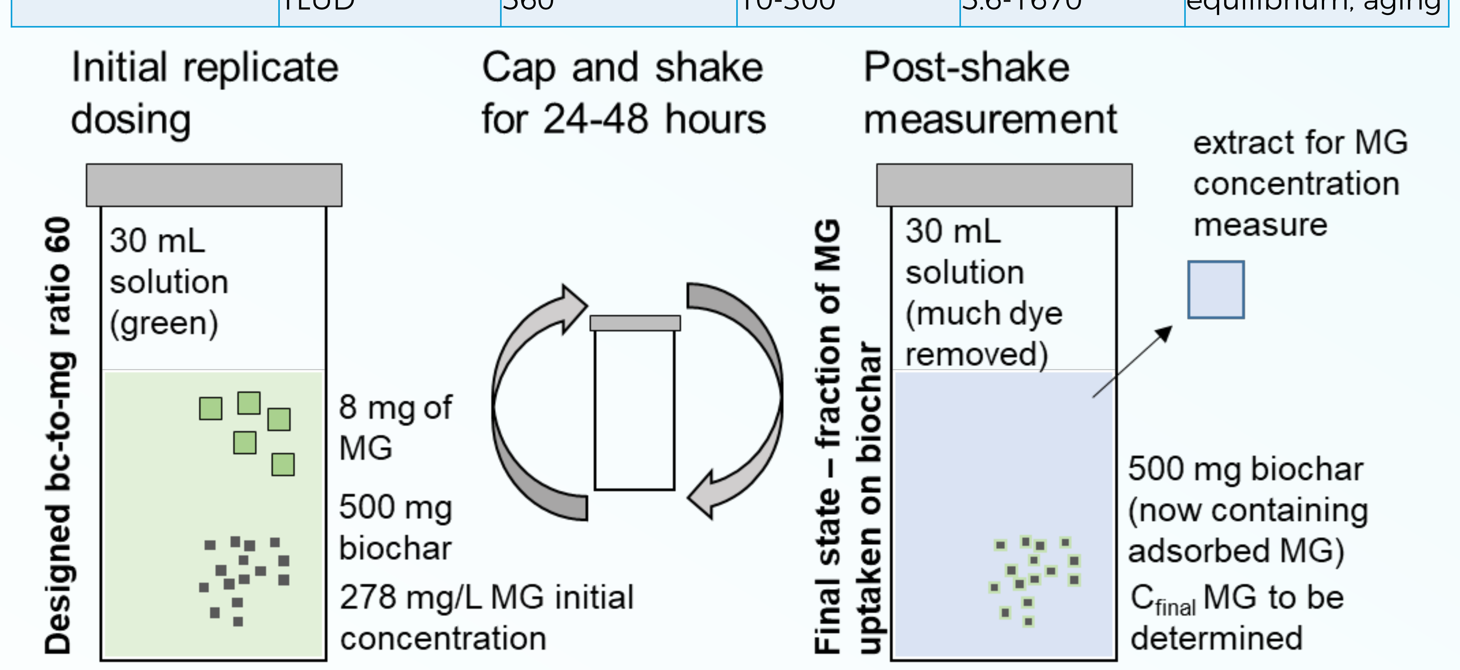
Research objectives

1. Compare the adsorption performance of common industrial dyes on biochars and relate to biochar production method, feedstock, and structure.
2. Ascertain the role of water quality conditions in the adsorption performance-pH, organic carbon, salinity
3. Develop a means to optimize biochar production to adsorb particular pollutants of interest for a runoff application.

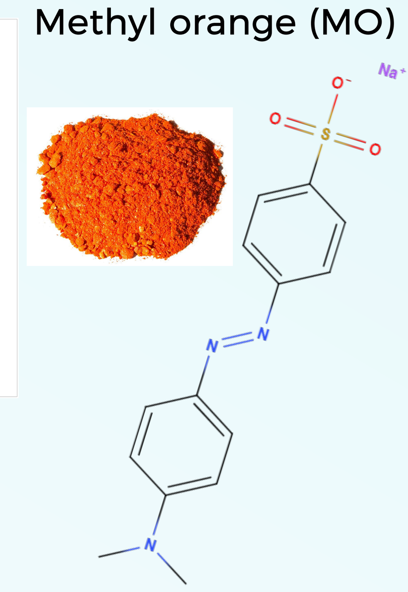


Experimental design: All shaker studies used 30 mL solution, 500 mg biochar, and conducted on both methyl orange and malachite green. Muffle furnace biochar created at constant 450 °C.

biomass	production method	specific surface area (m^2/g)	mass ratios (biochar to dye)	initial dye concentrations (mg/L)	study type used
pecan shell	muffle furnace	43	10-200	8.3-1670	equilibrium
	TLUD	430	10-200	8.3-1670	equilibrium, aging
cotton hull seeds	muffle furnace	490	10-200	8.3-1670	equilibrium
	TLUD	560	10-300	5.6-1670	equilibrium, aging

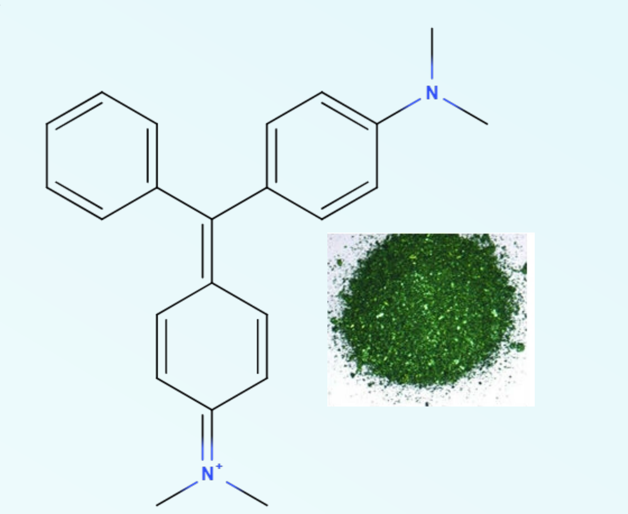


Methyl orange (MO)



MW 327 mg/mmol
pK_a 3.4
Solubility 5,000 mg/L
Max abs 465 nm (blue)
Dye type anionic (-)
Log K_{ow} unknown
Polar surface area 63.5 Å²

Malachite green (MG)



MW 365 mg/mmol
pK_a 10.3
Solubility 40,000 mg/L
Max abs 620 nm (red)
Dye type cationic (+)
Log K_{ow} 0.62
Polar surface area 6.2 Å²

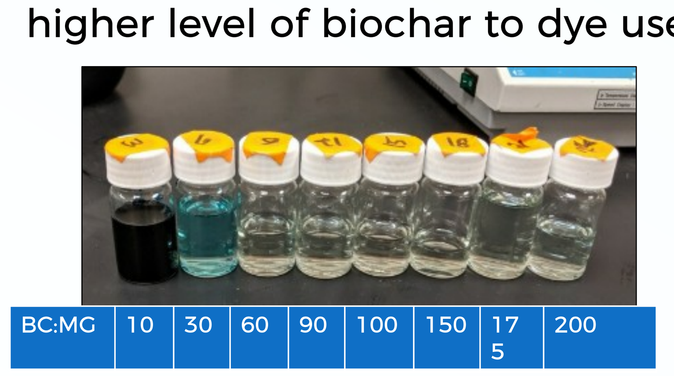
Mass balance method to determine adsorptive uptake on biochar

$$q_e\left(\frac{mg}{g}\right)=\frac{\left[C_i\left(\frac{mg}{L}\right)-C_f\left(\frac{mg}{L}\right)\right]\times 0.030\ L}{m_{biochar}(=0.500\ g)}$$

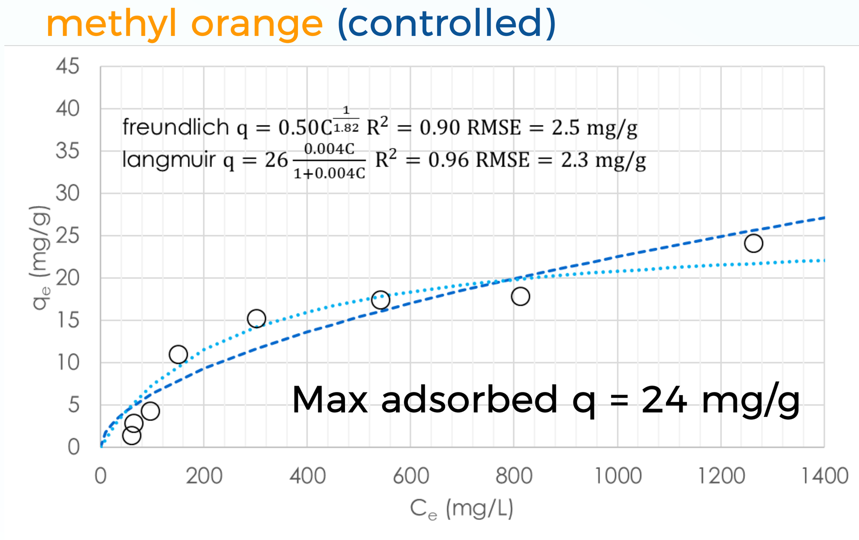
q_e final biochar solid phase concentration
C_i initial dye concentration (pre-shake)
C_f final dye concentration (post-shake)
m_{bc} mass of biochar added (pecan, cotton hull)

Results

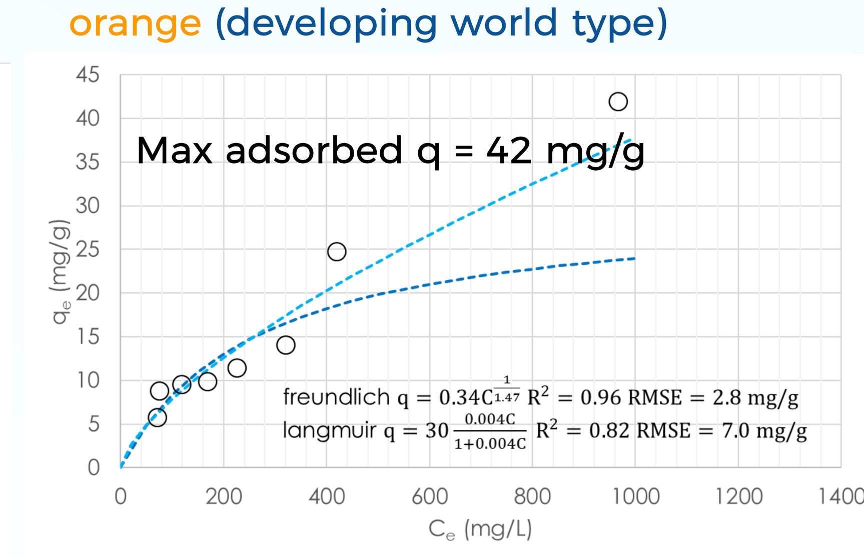
Visual difference according to higher level of biochar to dye used



Pecan shell muffle furnace – methyl orange (controlled)



Pecan shell top-lit updraft– methyl orange (developing world type)



Results

Summary of adsorption potential to date: The maximum concentrations adsorbed so far. K_d = distribution coefficient

feedstock	production method	dissolved (mg/L)	biochar (mg/g)	log K_d (L/kg)
methyl orange				
pecan	muffle furnace	26.8	38.5	3.2
	tlud	74.4	45.3	2.8
cotton hull seeds	muffle furnace	1260	24.3	1.3
	tlud	663	60.2	2.0
malachite green				
pecan	muffle furnace	63	16.2	2.4
	tlud	101	43.8	2.6
cotton hull seeds	muffle furnace	15	98.7	3.8
	tlud	80.1	61.8	2.9

Summary and future work

Important findings of the current experiment work

1. For methyl orange on both cotton seed hull and pecan shell biochars, the type of adsorption appears to be more like Freundlich type than Langmuir type. We suspect that the adsorption occurs in multiple layers and is physisorption type.
2. Interaction mechanism of methyl orange with biochar surface based more on the ***attraction between MO aromatic rings and aromatic surfaces on the biochar*** rather than on ionic functional groups on the biochar surface.
3. Hypothesize that malachite green interacts with biochar surface through negative functional groups as well as aromatic-aromatic interactions.
4. In general **malachite green adsorbs more strongly to biochars compared to methyl orange.**
5. It might be thought that TLUD biochars, which have greater specific surface area than muffle furnace biochars, would have the greatest adsorption capacity. We saw this behavior with methyl orange but only sometimes with malachite green.

Intended future work

- Improved isotherm studies for malachite green. Current studies sometimes at pH that may have caused MG to precipitate.
- Controlling pH and salinity in adsorption shaker experiments using buffers and either KCl or NaCl.
- Quantifying adsorption in developing world biochar using actual agricultural pollutants – herbicides, pesticides, nutrients.

Acknowledgements

The Killgore Faculty Research Grant Program at WTAMU funded an initial study for learning to produce and characterize biochar. That initial funding has allowed for better understood biochar samples to be examined for other material properties and adsorption behaviors.