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## Abstract

Biochar is a rich topic for research due to its numerous potential advantages. Biochar is a carbon-rich material made by carbonizing organic materials (e.g., manure, agricultural residues, woody biomass, etc.) in a zero or limited oxygen environment. Biochar is often presented as a panacea to cure many different limitations of soil. However, biochar is not all the same. Materials and processes used to create biochar have great effects on the resulting biochar's characteristics. The results of this study show a strong relationship between both feedstocks and temperature with properties of biochar. Higher pyrolysis temperature reduces the amount of biochar produced, increases its surface area, and reduces its cation exchange capacity (CEC). Different feedstock materials also produce highly different CEC. Studying properties of different biochar types at a specific production temperature is important to know its usable quantity and quality, in order to develop biochar that may improve specific limitations of different soils.

## Introduction

Biochar has many potential benefits as a soil amendment. Biochar is added to soil with intent to sequester carbon, improve soil physical and chemical qualities, or bind contaminants and heavy metals (Srinivasan and Sarmah, 2015). Biochar has a high density of negative surface charge, a diversity of surface functional groups, and high surface porosity (Liang et al., 2006). All these properties determine biochar sorption of chemical molecules. However, all biochar does not have the same chemical and physical properties (Mukherjee et al., 2013). Both the feedstock type and pyrolysis conditions determine the physical and chemical properties of biochar (Downie et al., 2009; Novak et al., 2009; Ronse et al., 2013; Ahmad et al., 2012; Keiluweit et al., 2010). **It is therefore important to understand the properties and production methods that render biochar useful or harmful to specific desired chemical-physical properties of soil.**

The cation exchange capacity of a biochar is important for soil amendment which aids plant growth (Atkinson et al., 2010), and aliphatic functional groups provide nutrient exchange sites for retaining soil nutrients (Peng et al., 2011). Aliphatic functional groups also determine its hydrophobicity (Novak et al., 2009). Therefore, biochar use as a soil amendment is only effective if the proper characteristics such as functional groups are produced. Before applying biochar to soil, It is important to know biochar's productivities, cation exchange capacity and surface area and topography of biochar.

Biochar is typically made at a low pyrolysis temperature of  $\leq 400$  °C. Low temperature gives biochar numerous surface functional groups and a high cation exchange capacity (Gaskin et al., 2008; Glaser et al., 2002; Novak et al., 2009). Aliphatic functional groups present in biochar improve its sorption capacity (Sun et al., 2011). On the contrary, biochar production at  $> 400$  °C increases the aromaticity of the biochar and decreases surface functional groups because of dehydration and decarboxylation (Baldock & Smernik., 2002; Downie. 2009).

This research uses a range of feedstocks and temperatures to identify materials and conditions needed to make biochar with high CEC and benefits to soil hydraulic properties.

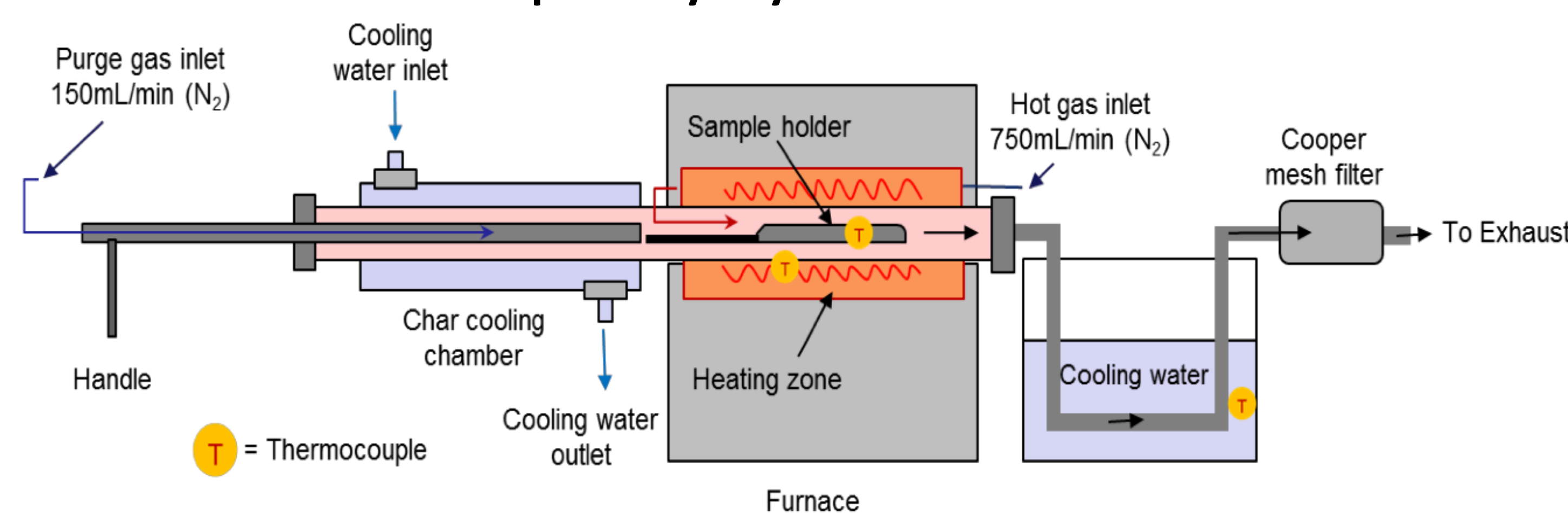
## Methods and Instruments

Four biomass feedstocks:

- Tamarix aphylla wood with bark
- Anaerobic digester (AD) fiber
- Perennial rye straw
- Arundo biomass

were air-dried and milled. Large particles were removed by sieving to  $<1$  mm. Feedstocks were pyrolyzed at four temperatures (300, 400, 500, 600°C) using auger/spoon pyrolysis reactor in Biosystems Engineering Dept. at WSU.

### Spoon Pyrolysis Reactor



**Biochar yield:** measured mathematically as described by Novak et al., (2009)

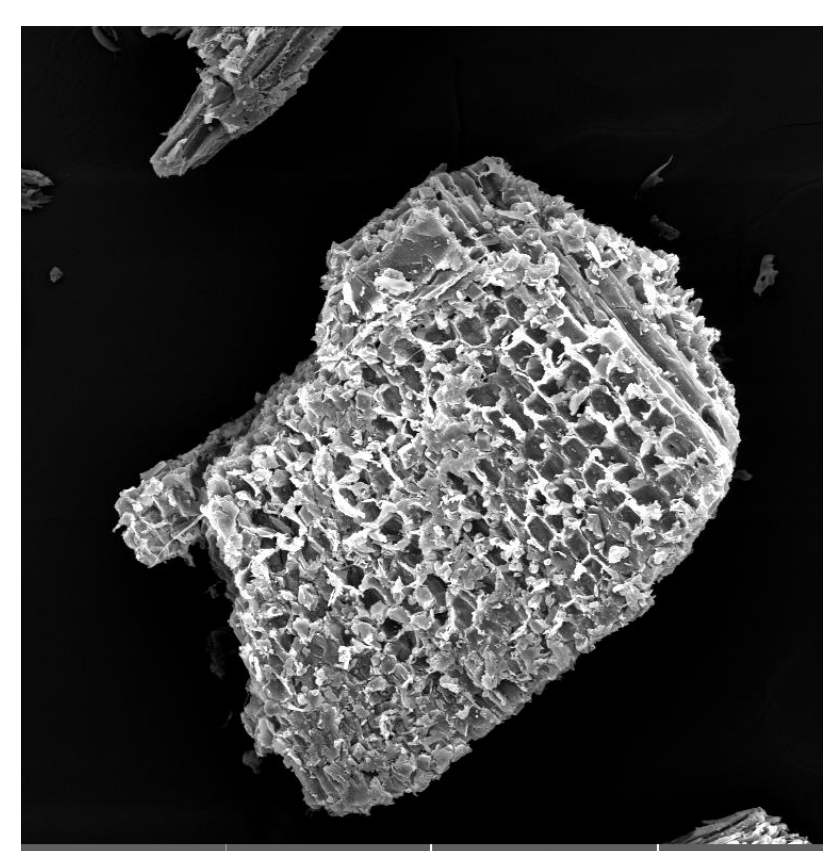
**Surface Area:** measured by carbon dioxide sorption at 273K using multipoint Brunauer, Emmet and Teller (BET) analysis on micromeritics TriStar II PLUS Surface Area and Porosity Analyzer (Norcross, GA, USA). Prior to analysis, samples vacuum degassed at 150°C for 12 hours. Then, adsorption isotherms of carbon dioxide were determined at pressure  $p/p_0=10^{-5}$  to  $p/p_0=0.03$  with 75 set equilibration points. Then Dubin-Radushkevich (DR) equation used to estimate surface area and micropore volume.

**Cation Exchange Capacity (CEC):** determined by method of Munera et al. (2018). Biochar samples were washed with diluted solution of HCL three to five times to remove ash, then washed in distilled water until pH became 7 and EC less  $0.2 \text{ ms cm}^{-1}$ . Samples were saturated with  $\text{NH}_4$  and then with K after washing with alcohol. Ammonium measured in the final extract is equal to the total CEC.

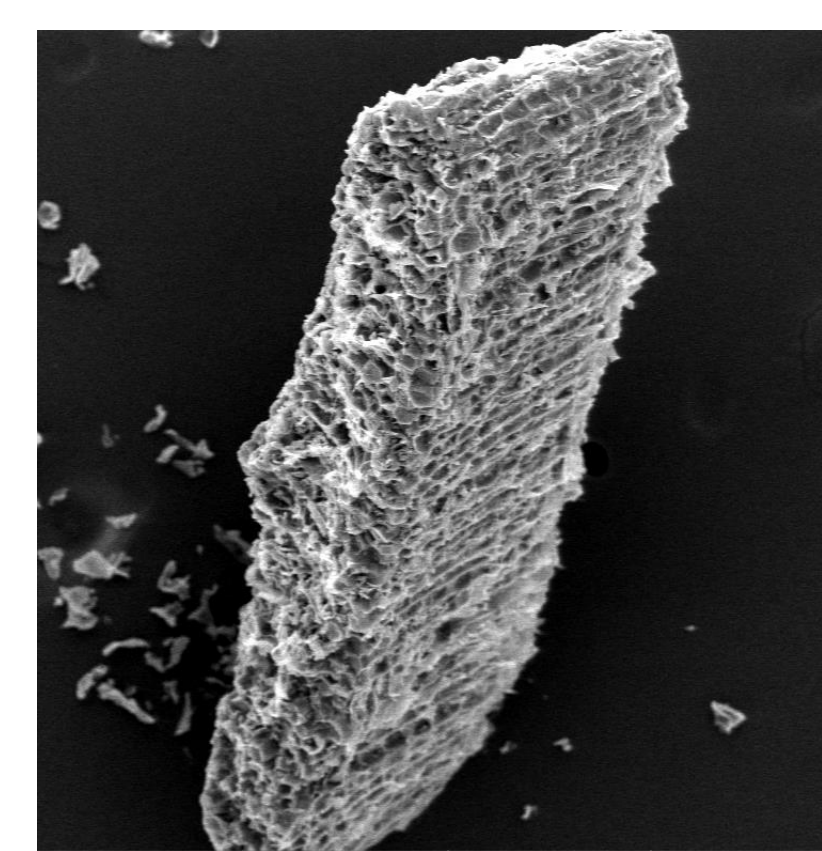
## Images

### Scanning Electron Microscopy (SEM) :

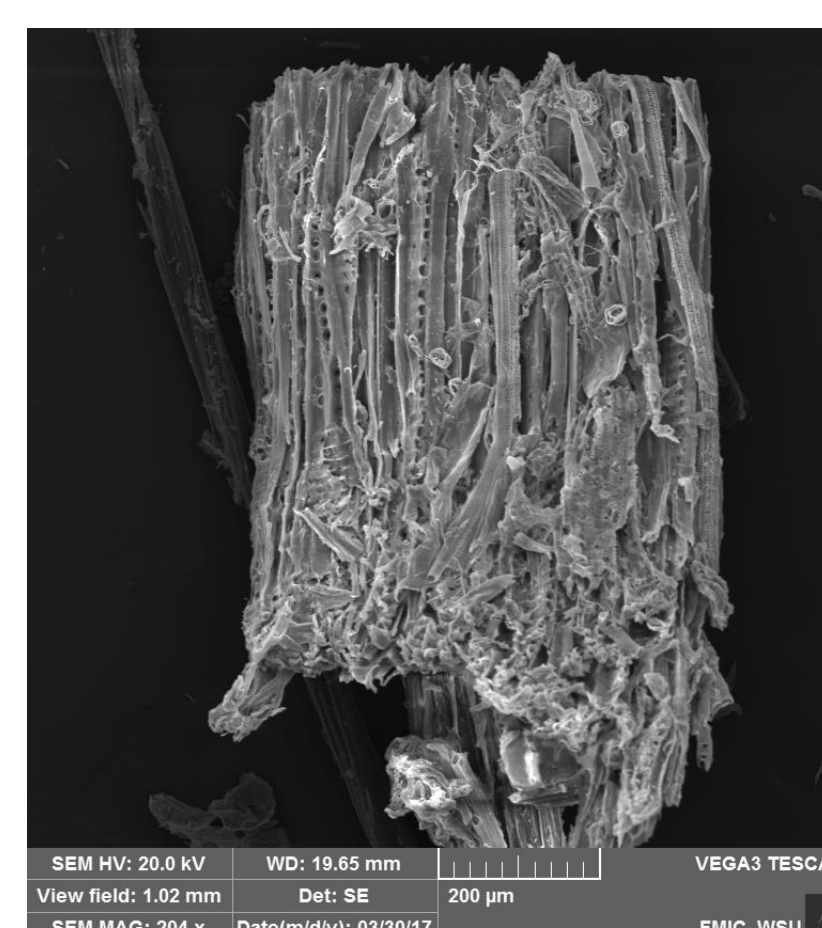
The samples pyrolyzed at 300°C were placed on carbon tabs and SEM stubs before gold plating. Samples were then examined using the Hitachi SEM.



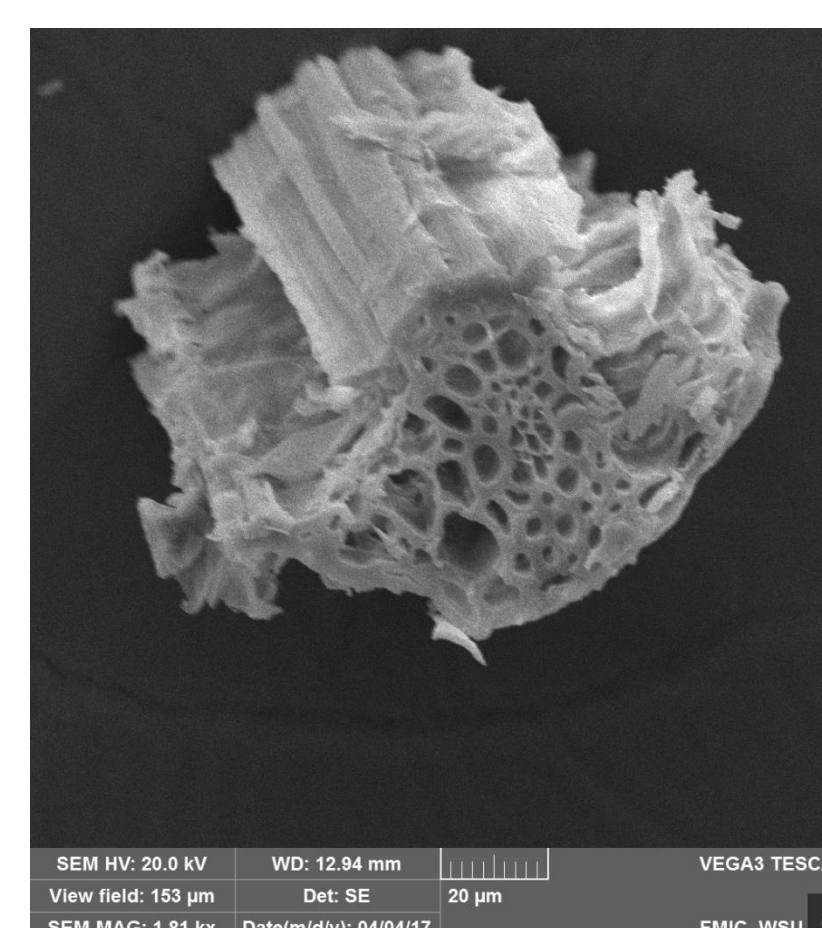
Tamarix aphylla wood



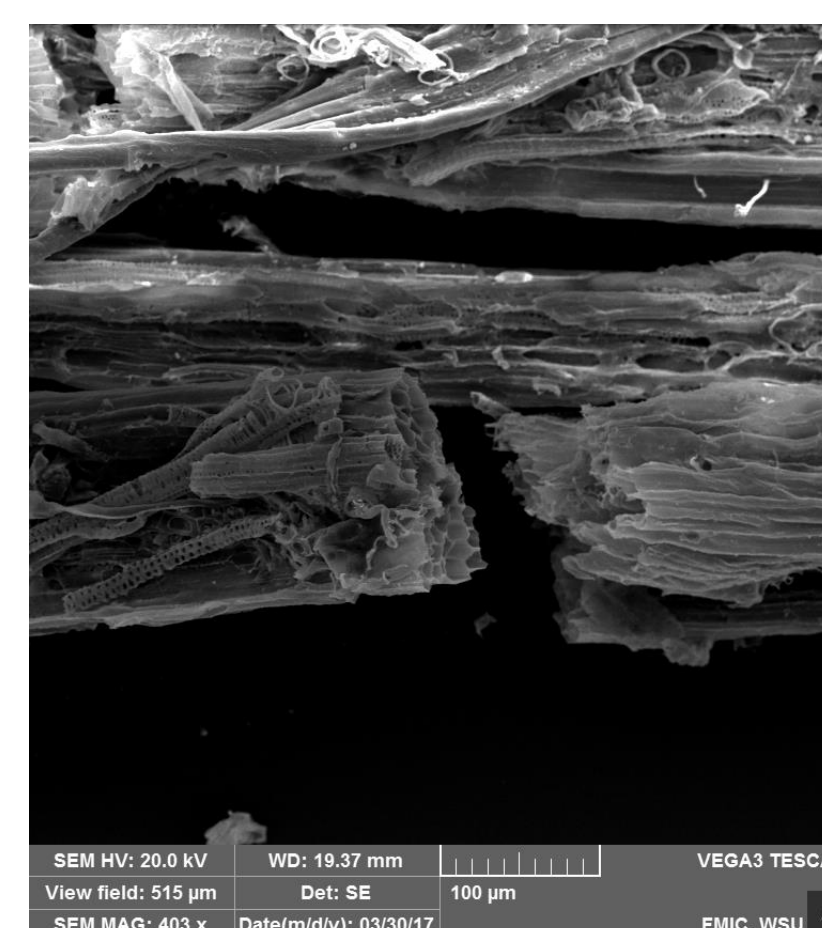
Tamarix aphylla Bark



Arundo Biomass

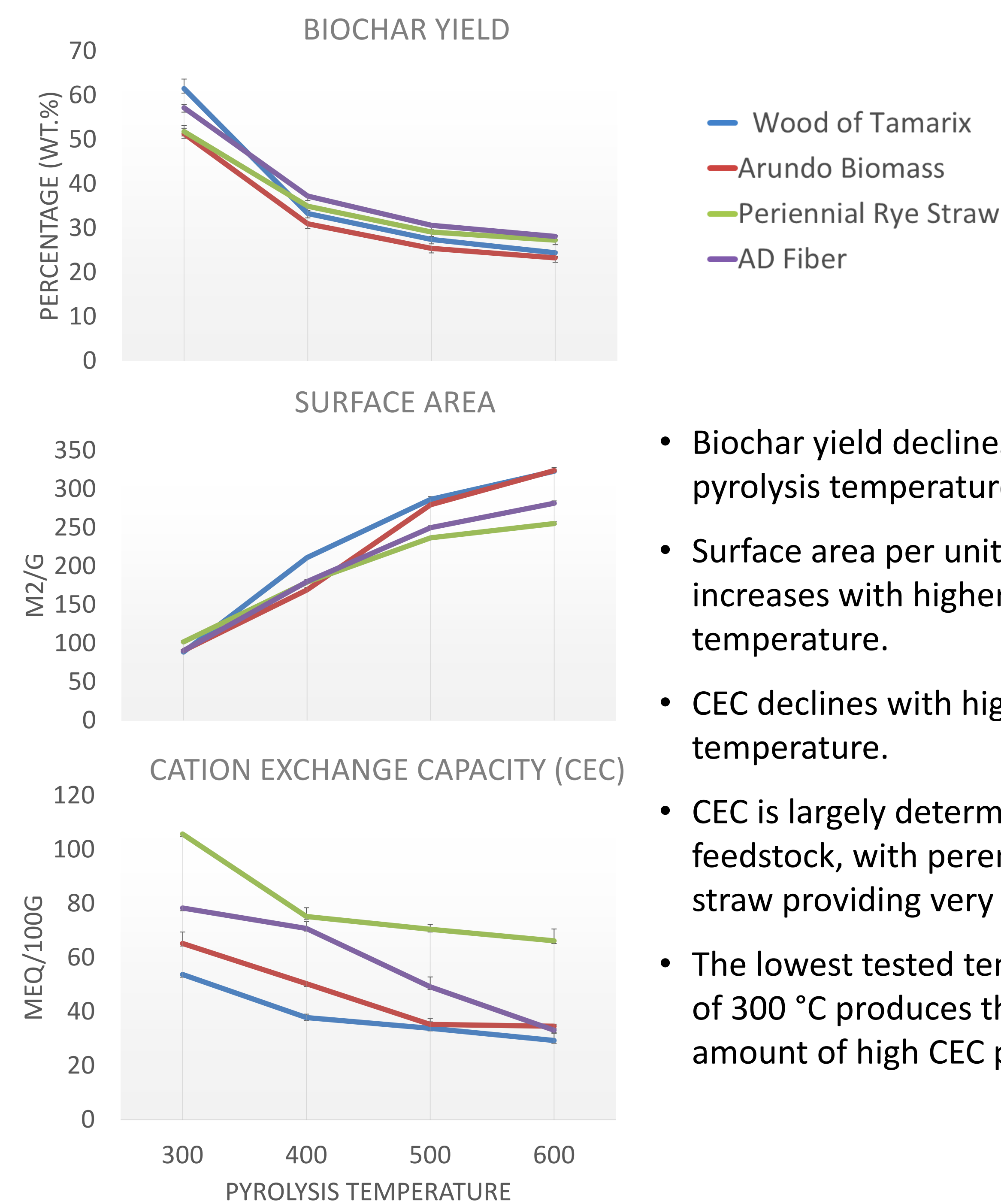


Perennial rye straw



Anaerobic Digester (AD) Fiber

## Results



- Biochar yield declines as pyrolysis temperature increases.
- Surface area per unit mass increases with higher temperature.
- CEC declines with higher temperature.
- CEC is largely determined by feedstock, with perennial rye straw providing very high CEC.
- The lowest tested temperature of 300 °C produces the greatest amount of high CEC product.

The results of linear regression analysis show a significant effect for both pyrolysis temperature and feedstock on biochar characteristics. Pyrolysis temperature affected biochar yield, surface area, and cation exchange capacity of biochar from every feedstock ( $p < 0.01$ ,  $R^2$  0.78-97), except surface area of perennial rye straw. Likewise, feedstocks had a significant effect on biochar yield, surface area, and cation exchange capacity at every temperature ( $p < 0.05$  with  $R^2$  0.11-0.81).

## Conclusions

Feedstock properties and biochar production methods affect the resulting biochar CEC and surface area. The examined types of biochar could be used in agricultural applications to increase cation exchange capacity (CEC) and surface area in poor or sandy soils. Further research is needed to investigate the impact of pyrolysis temperature on other important characteristics such as aliphatic functional groups which determine hydrophobicity (Novak et al., 2009).

## References

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