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Exploring the role of biochar as a soil amendment

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The anaerobic, thermal decomposition of biomass leads to the formation of a stable carbonaceous adsorbent that is termed biochar (BC). In the recent past, BC has gained remarkable research interest as a cost effective alternative to activated carbon. Major areas of BC application include the improvement of soil quality and health, pollution remediation, and climate change mitigation. Factors that govern the characteristics of BC include pyrolysis temperature, feedstock type and the nature of the value additions done. Therefore, it is essential that these factors are optimized in order to reap maximum benefit from BC. Pre- or post- modifications can have a significant impact on the surface area, pore size distribution, and surface functionalities of the BC. Upon registering in 2017 for a Master of Philosophy (MPhil) degree in University of Colombo, extensive research and literature survey has been conducted to investigate the efficacy of BC in environmental management. The MPhil study was titled "Enhancing crop productivity and minimizing toxic heavy metal uptake of four economically important agricultural plants in Sri Lanka by using Tea waste biochar", and was broken down into several important segments.

The first stage of the MPhil project involved the characterization and production of BC. Solid waste accumulation in Sri Lanka has increased due to the progress in industrial, urban and economic development. Therefore, disposal of solid waste is becoming an area of concern. Tea is a popular beverage consumed by people worldwide and around twenty percent of it comes from Sri Lanka. Therefore, the waste that is generated by its production is significantly high. Unwanted accumulation of tea-waste can lead to the adulteration of our tea exports. As evident from available literature, tea-waste has attracted attention as a potential biomass for BC production. The porosity of tea-waste biochar (TWBC) is, however, not as high as in the other types of BC. To increase its capacity, researchers have incorporated many physical and chemical modifications. Nonetheless, a comprehensive evaluation of the changes in physicochemical properties that take place upon modification was not done before. Bridging such a gap becomes beneficial for any preliminary study that uses tea-waste as a feedstock. Tea - waste was pyrolyzed at three different temperatures and subjected to acid modification. In the work, three of the most frequently used types of acid modifications; hydrochloric, nitric and sulfuric acid modifications, were used to establish a comparison in physicochemical properties between the raw and modified TWBC.

Surface morphology, surface acidity, surface functionality, ultimate and proximate analysis, point of zero charge, cation exchange capacity (CEC) and thermal stability are physicochemical properties that have been examined. It was found that with increasing temperature, the amount of carboxylic acids that were present on the BC surface decreased, the hydrophobicity of the BC increased and the CEC decreased. The nitric acid modification led to an increase in the nitrogen moieties on the BC surface and led to an increase in the surface area as well. Upon modification with sulfuric acid, the pore walls were destroyed and the pore volume was enhanced. This research, therefore, gave an insight into the specific morphological alterations that took place upon acid modification and will help scientists in manipulating the chemistry related to TWBC. The research findings were published in RSC Advances under the title "The influence of three acid modifications on the physicochemical characteristics of tea-waste biochar pyrolyzed at different temperatures: a comparative study". The journal had an impact factor of 3.049 and a contribution was made as the first author of the publication. The fruits of the project were reaped after two years of hard work and a significant portion (~eighty percent) of the experiments were conducted at IChemC.

It was required in the project to determine the metallic composition of BC. Though techniques are available for the determination of surface composition, in order to find the metallic composition of the entire BC sample, it had to be digested. The challenge was to come up with a fast and cost effective open vessel digestion method. Also, the development of a microwave digestion

method was tested as well. Although EPA methods for digesting organic, siliceous and sludge based matrices existed in literature, there was no method specified for the digestion of carbonaceous material. Moreover, the reagents used in existing methods were hazardous and consumed a lot of time to reach reaction completion. An attempt was made to fill this research gap by using different types of acid mixtures on nine different types of carbonaceous adsorbents. For this purpose, TWBC and king coconut BC produced at three different temperatures were used alongside Douglas fir BC, steam activated coconut shell BC and sludge waste derived BC. Experiments revealed that mixtures of fuming nitric acid digested all the samples and gave minimum matrix effect. Except for peroxide mixtures, other reagent mixtures were successfully utilized in the microwave digestion procedure. The findings were published in Chemosphere under the title "Microwave and open vessel digestion methods for biochar" which had an impact factor of 5.108. A contribution was made as a co-author of the publication. It is important to mention that the research facility at IChemC was used to the fullest for all the experiments related to this project.

Testing the effect of BC amendment on plant growth was the final part of the MPhil study. The crop trials were done at the Wayamba University of Sri Lanka. However, evaluation of the greenhouse experiments were done at IChemC. Red Onion was selected for the experiment as it is an important commercial crop that is used for its medicinal and flavor properties. Soil was amended with raw and modified TWBC at different application rates prior to planting Red Onion. A comparison was made of the differences in shoot, and root length in addition to the number of bulbils and leaves that grew on the plants. A microbial study was conducted to assess the influence of BC amendment on the growth of microorganisms. The results showed that microorganism populations were high in the modified BC amended pots. Higher crop yields were observed in pots amended with modified TWBC. The results of the study are yet to be published though the completed thesis has been submitted for examiner review. Going very much in par with the final research work of the MPhil study, a chapter on "Biochar for Sustainable Agriculture: Nutrient Dynamics, Soil Enzymes, and Crop Growth" for the book "Biochar from Biomass and Waste" was published. This chapter managed to discuss in depth the topic of sustainable agriculture and how BC influenced it. It is evident that the physicochemical properties of soil such as pH, soil organic matter, water-holding capacity, water infiltration and soil aeration are all affected by BC application. Moreover, BC can enhance the retention of nutrients in soil. Contribution to the chapter was made as the first author.

During this time, a review article was written which was titled "Biochar Based Removal of Antibiotic Sulfonamides and Tetracyclines in Aquatic Environments: A critical review". The work was published in Bioresource technology which had an impact factor of 5.807. The antibiotics tetracyclines and sulfonamides are pharmaceutically active compounds that are considered as contaminants of emerging concern. Biochar has been used extensively as a cost effective alternative for the adsorption of these compounds. However, a research gap existed as only minimum attention was given to the mechanisms by which antibiotics were taken up by BC. The article's main purpose was to provide an in detail understanding of the sorption mechanisms related to BC-antibiotic uptake by revisiting the relevant literature. Bringing this scattered knowledge to one place has given a clear understanding of how contaminants are removed by BC. It also provides valuable information on how to best engineer BC to gain maximum adsorption capacity for these analytes. The review article is a frequently read piece of work. Currently, it has over a hundred citations in google scholar and was nominated for both the Presidential award for scientific research 2017 and the Bioresource technology, most highly cited review article of the year award 2018. A noteworthy contribution has been made as the first author of this review.

Magnetization is an important modification as it enables the ready remediation of exhausted BC from water systems. A manuscript is in preparation for a research that incorporated a magnetic modification on TWBC for the adsorption of three different metal ions. Magnetization has also been done for BC made from Kohila (*Lasia Spinosa*). A review article regarding the uptake of estrogen using BC is under preparation as well. While serving as the research assistant of IChemC (2017-2019), there has been a substantial contribution made to the prevailing knowledge on BC. Undergraduate research students have also benefitted from this expertise and knowledge, especially when it came to laboratory skills and work ethic.