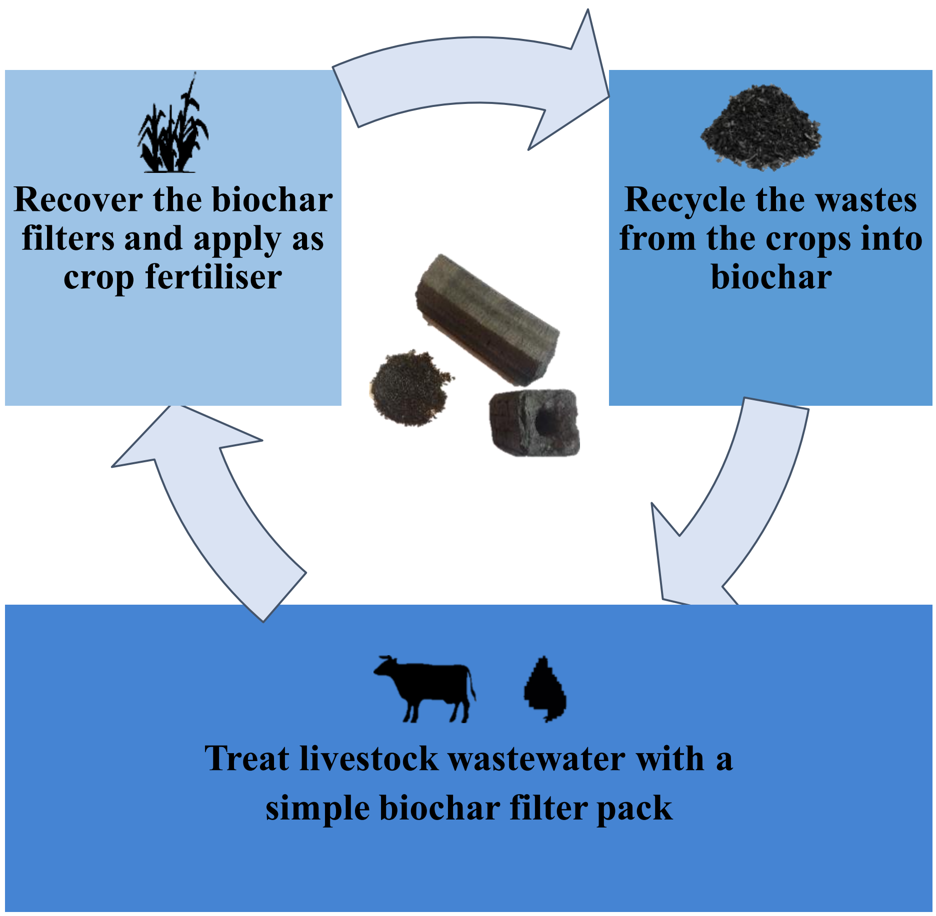
Entry to the Stockholm Junior Water Prize 2018

RECYLING WASTE INTO BIOCHAR

A novel, sustainable model of wastewater filtration and crop fertilization for the agricultural industry



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About Minh Nga Nguyen

I am a year 12 student, at Sydney Girls High School, Australia, with my interest being in developing methods of water treatment using waste or unwanted products. In the past, I have engineered a duckweed bioremediation model, and garnered the inspiration for this biochar project upon a trip back to my home country of Vietnam. Whilst travelling through the countryside, I was extremely shocked to witness the severity of the agricultural industry's environmental pollution, in which the poor management of both plant and animal waste-products contributed greatly to air and water pollution. Thus, I felt prompted to help farmers, especially in developing nations, prevent these types of pollution from occurring in an economic and sustainable manner. From this stemmed my project's idea of multi-purpose biochar. I have been extremely grateful in how from these humble beginnings that my research has received the 1st Place investigations award at the 2018 Australian BHP National Billiton Science and Engineering Awards, thus offering me the opportunity to compete in America for my second time at the 2018 International Science and Engineering Fair. In the future, I aspire to become an environmental engineer working in corporation with NGO's and DFAT to extend Australia's scientific aid overseas to third world nations. Beyond my passion for science, I am a school student ambassador and have been awarded my school's 2018 Student Leadership Medal.

ABBREVIATIONS

CC- Corncob biochar

MCC- Modified corncob biochar

BB- Bamboo biochar

RH- Ricehusk biochar

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- My parents for assisting throughout the project with the purchasing of materials
- University of Technology Sydney (UTS), who kindly lent me dosage pumps, chemicals, and assisted with spectrophotometer analysis of my water influent and effluent samples

SUMMARY

The agricultural industry has a severe toll on our environment, with its rising output of animal wastewater being a major cause of water nutrient pollution (eutrophication), whilst simultaneously, air pollution occurring as agricultural plant byproducts are burnt as a means of disposal. This project aimed to address both these environmental issues, by recovering and recycling these polluting agricultural plant wastes into a dual-purpose biochar. This study sought to address gaps in previous biochar research, in which no model of biochar has yet been engineered, and in which there has been minimal in-situ studies of biochar that measure the impact of competitive adsorption of nutrients.

To achieve these aims, a comprehensive in-situ study was conducted, that compared the effect of different filtration conditions and plant feedstocks on biochar's adsorption of animal wastewater nutrients. Based on results and consideration of cost and time factors, a novel model of biochar's most economical and efficient bioadsorbent use was engineered. This model involves bamboo biochar's use over a 1 hour detention time and 36 hour running time. Running time should be increased to 72 hours if phosphate levels are concerning, as this duration can maximise the phosphate adsorption. Through this model, bamboo biochar's effectiveness was enhanced so that it filtered wastewater to meet Australian effluent guidelines, with its bioadsorbent capacity (3.78 mg nutrients/g biochar) being similar or exceeding that of currently applied bioadsorbents. Additionally, exhausted biochar filters were suitable for reuse as fertilisers, improving plant growth at a similar rate to the commercial fertiliser trialed. Thus, an environmentally-conscious cycle was developed, in which problematic and polluting agricultural plant byproducts such as bamboo, corncob can be continuously recycled into a productive, dual-purpose biochar filter and fertilizer. As biochar filters can then release the nutrients they have adsorbed to aid growth of plants, whose wastes later become biochar, the model is sustainable. It can benefit the agricultural industry (especially for small-scale farms in developing nations), as follows.

Firstly, biochar's strong bioadsorbent capacities can mitigate both air and water pollution, as this model is essentially utilizing plant waste to treat animal wastewater. Biochar is acting as a medium taking nutrients where they are harmful, in the animal wastewater, and releasing them where they are valuable, in the soil. Due to the low cost of this model's feedstock and its self-sustaining nature, this model is also more viable financially compared to current chemical and biological wastewater treatments. It is accessible for global use because of biochar's multiple productive applications, with economic benefits also being offered through how exhausted biochar filters can reduce commercial fertilizer costs. Furthermore, this model involves simple decentralized systems that farmers can easily implement, with no skilled operators required.

I. INTRODUCTION

I.1. Eutrophication is a type of water pollution caused by the entry of excess nutrients into water bodies, affecting major water bodies worldwide including Lake Erie (USA) and Lake Dianchi (China). It causes toxic cyanobacteria blooms that decrease dissolved oxygen levels, creating hypoxic conditions that pose a high risk to ecosystems, potentially leading to ecosystem collapse and lowered biodiversity. Eutrophication also economically impacts fisheries and tourism industries (Chislock, 2013).

Photo 1: Eutrophication in Lake Erie, USA, one of the Great American Lakes (Source: Cleveland Museum of Natural History, 2017)

I.2. Agricultural wastewater and livestock runoff heavily contribute to eutrophication, as 2/3 of the nutrients animals consume are excreted (Brooks, 2010). For example, in China's first pollution report, agricultural activities were responsible for 67% of the nation's phosphorous and 57% of its nitrogen discharges (Watts, 2010). Currently, biological and chemical methods such as struvite use are used to manage livestock runoff (Kizito et al., 2015). However, these processes are often costly, highly pH sensitive and usually do not remove ammonium effectively (Sica, 2014).

Photo 2: Polluting Livestock operations (EPA, 2016)

I.3. Agricultural plant by-products and crop residue are often burnt in developing nations, which releases carbon dioxide to the atmosphere, contributing to climate change. (Vu et al,. 2017).

I.4. Biochar is a carbon-rich charcoal residue produced through anoxic pyrolysis at temperatures from 300-1500^{0}C of agricultural wastes (Zheng, 2010). It has favourable characteristics for adsorption such as a high surface area, porosity and anion charge, and has shown potential in adsorbing pollutants including heavy metals, organics, herbicides (Zheng et al., 2010; Taghizadeh-Toosi et al., 2012). However, past studies have focused primarily on its chemical characteristics rather than maximizing its practical effectiveness (Talberg, 2009). They have mainly been short term in controlled environments with synthetic water, with more in-situ studies with real wastewater needed to account for competitive adsorption. Models of biochar's practical usage are also yet to be developed, with research also being lacking in terms of exhausted biochar's effectiveness as a fertiliser. The limited understanding in biochar's practical applications have thus restricted its widespread use.

Photo 3: Biochars (ETH, 2014)

II. MATERIALS AND METHODS

II.1. Materials and Equipment

- Oven
- Steel can
- Gloves
- Sieves: particle sizes 0.3-0.6, 0.6-0.1 mm
- Mortar and pestle
- 0.5 M NaOH
- 6M Hydrochloric acid
  Distilled water
- Dosing pump
- Corncob (CC) biochar
- Modified corncob biochar (MCC)
- Bamboo biochar (BB)
- Rice hus biochar (RH)
- Fertiliser (Hortico: total nitrogen 12.5% w/w; total phosphorus: 2%)
- Broccolette plants
- Richgro garden soil
- Plant pots
- Ruler
- Spectrophotometer
- Human urine
- Test tubes
- Beakers
- Electronic balance

II.2. Method

Stage 1- Biochar pyrolysis and preparation

1. Pyrolyse corncob at 500^0 C in closed steel can (anoxic conditions) for 3 hours to CC biochar
2. Produce modified corncob biochar (MCC) by using half of above quantity of CC, and treating it with 6M HCl for 8 hours, then 0.5 M NaOH for 24 hours (based on the procedure of Vu et al., 2017).
3. Grind and sieve CC, MCC and commercially produced bamboo biochar (BB), commercially produced rice husk biochar (RH) into particles 0.3-0.6 mm
4. Wash biochars with distilled water and dry in laboratory oven for 3 hours

Photo 4.
(a) Above left: producing CC biochar
(b) Above right: CC biochar before sieving)

Stage 2- Column studies

Component 1- Comparison of different biochars

5. Weigh 3.50 g of CC, MCC, BB and RH biochars and pack them into 4 plastic filter columns (diameter 15cm), volume of 15mL/filter
6. Pump human urine into 4 filter columns simultaneously using dosage pumps, flow rate of 40mL/h
7. Collect effluent samples periodically during 24 hours

Based on the results of component 1 and the global accessibility of materials, corncob and bamboo biochars were selected for components 2 and 3 of the study

Component 2- Investigating the effect of different detention on nutrient adsorption

Photo 5

(a) Above left: single column tests

(b) Above right: multiple columns of CC biochar running under same influent

8. Prepare 3 CC biochar filter columns, each column packed with 3.50 g CC biochar.
9. Run 3 CC biochar filter columns in a series mode (Photo 5b)
10. Collect effluent samples from different columns (corresponding detention time from 0.33h to 1h) periodically every 12 hours over 72 hours

Component 3- Investigating the effect of running time on nutrients adsorption

10 Repeat steps 8 and 9 using BB (instead of CC)

11 Collect effluent from column 3 (detention time of 1h) after periods of 12 hours over 72 hours

Component 4- Measurement of nutrient concentration in influent, effluent samples

11. Measure samples' ammonium, nitrate, nitrite, phosphate levels with spectrophotometer

Stage 3- Testing exhausted/used biochar as a fertiliser

12. Place equal amounts of soil into 8 plant pots, each with 1 brocolette sapling
13. Mix equal amounts of used/exhausted CC biochar (3.50 g) into two plant pots,
14. Repeat process with used BB biochar with another 2 pots
15. Leave another 2 pots to act as control pots without biochar
16. Mix 0.09 g of Hortico Plant and Vegie commercial fertiliser equally into 2 plant pots (contains similar nutrient levels as masses of used CC, BB)
17. Place all samples under clear covering (Photo 6)
18. Water each plant with equal amounts of water on a daily basis
19. Measure each plant's height, number of leaves, root length. Repeat measurements weekly over 6 weeks

Photo 6: 8 pots (L to R):
2 controls, 2 commercial fertiliser,
2 CC and 2 BB plants

III. RESULTS

III.1. Comparison of removal of nutrients by different biochars

The performance of different biochars in removing nutrients from urine is presented in Figure 1. In order to compare the performance of the different biochars properly, the 4 filter column trials were run simultaneously over 3 days with the same influent, to minimise the effect of varying urine composition.

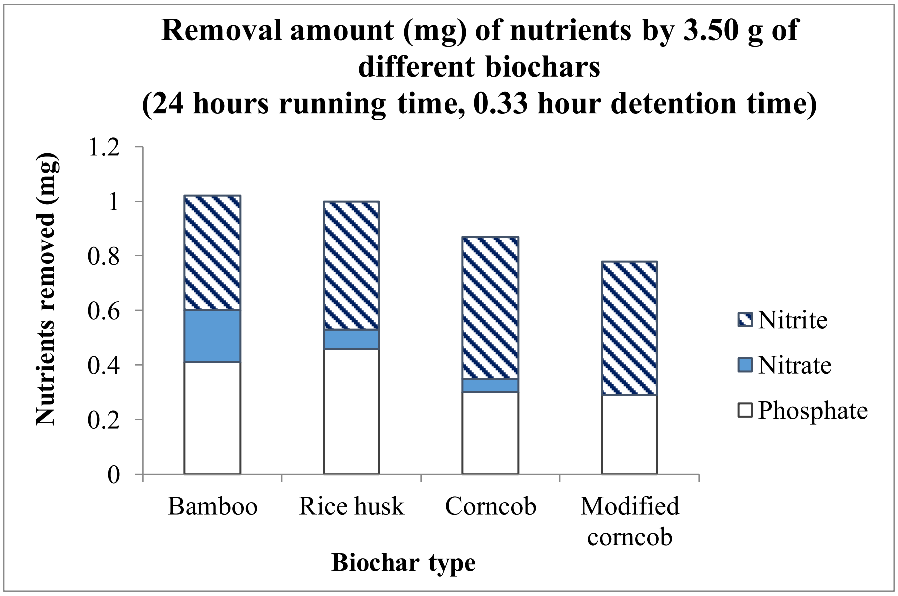

Figure 1. Comparison of removal amount (mg) of nutrients by 3.50 g of different biochars in column test *(Influent pH: 8.7-8.93; phosphate concentration: 1.38-2.19mg/L; ammonium concentration: 4.6-8mg/L; nitrate concentration: 8.8-11.3mg/L; nitrite concentration: 0.42-1.65mg/L)*

Results from these first set of experiments show that the rice husk biochar displayed the highest removal amount of phosphate, at 0.46 mg of PO_4^{3-} being adsorbed. However, it is worth noting that there was only a slight difference of a maximum 0.16 mg between the amount of PO_4^{3-} adsorbed across the 4 different biochar types. This denotes all four biochar materials have a similar capacity and suitability for phosphate adsorption, and the choice of material employed is dependent on which material is most accessible and cost-effective. All biochar materials were fairly comparable in terms of their nitrite reduction ability, differing at most by 0.10 mg. In term of nitrate, bamboo biochar could remove 0.19mg, higher than other materials (0-0.07 mg of nitrate removed after 24 hours for modified corncob, corncob and rice husk).

Regarding ammonium removal, the ammonium concentration of the effluent was only slightly different compared to that of the influent. This result does not correspond with previous results of past literature (Vu et al., 2017). The reason for the low removal of ammonium from the urine can be explained by the prolonged storage time between influent collection and spectrophotometer measurement (1 week). At a neutral pH and typical wastewater temperature (20-30^0 C), most ammonium ions are in ionized form. However, at a higher pH of 9.3 (similar to the basic pH conditions of this study's urine of 8.9-9.17), the number of hydroxyl ions rises, and the concentration of unionized ammonium becomes equal to the concentration of ionised ammonium (Siegrist et al., 2013). Therefore, in these experiments, a significant level of ammonium in the influent samples could have evaporated during the 1-week storage before spectrophotometer analysis. Hence, the ammonium measured in these first set of trials was not accurate. To address this potential source of error, in subsequent trials, the period between urine collection and column tests, and between sample collection and spectrophotometry analysis, were reduced to 12 hours and 2 days respectively. In addition, sampling containers were filled completely with influent to minimize the rate of ammonium volatisation.

III.2. Effect of detention time on nutrient removal

Tables 1 shows the effect of different detention times on the nutrient removal performance of corncob biochar filters.

Table 1. Removal amount (mg) of nutrients by corncob biochar under different running times and detention times (number of filter columns) (*Influent pH: 8.84-9.01, Influent phosphate, ammonium, nitrate, and nitrite concentrations were respectively: 1.37-3.66 mg/L; 9.0 mg/L-29.8 mg/L; 8.8-14.9 mg/L; and 0.43-0.6 mg/L)*

Detention time (h)	**0.67**		**1**		
Running time (h)	**24**	**36**	**24**	**36**	**72**
NH_4^+	5.72	9.42	6.63	10.39	12.89
NO_3^-	0.92	1.98	1.46	2.88	8.21
NO_2^-	0.11	0.12	0.12	0.15	0.29
PO_4^{3-}	0.97	1.02	0.98	1.06	3.10
Total nutrients removed (mg)	**7.72**	**12.54**	**9.2**	**14.48**	**24.49**

Within this second batch of column studies, ammonium was adsorbed at a high amount, corresponding to past literature now that ammonium volatisation was mitigated; with a maximum of 12.89 mg ammonium being removed under 3 columns over a 72 hours running time (corresponding to 1.48 mg ammonium/g CC).

It is identified that an increase in detention time from 2 to 3 columns had a positive effect on ammonium adsorption.

With an increase in detention time, phosphate removal also significantly rose (observed if figure 1 and table 2 are compared), with more than a 300% increase in phosphate removed upon increasing detention time from 0.33 hours to 0.67 hours during the 1st 24 hours of running time. However, in terms of phosphate removal, 3 filter columns are not deemed to be necessary as the amount of phosphate removed did not significantly heighten under 3 filter columns. This marked difference demonstrates that to maximize phosphate removal, 2 filter columns are recommended for use.

Similar to the phosphate, 2 columns and double the detention time increased the nitrate removal amount greatly (nearly 19 times). Differing from the phosphate removal however, three columns significantly maximized the nitrate biochar adsorbed, with approximately 150% greater nitrate adsorption under these conditions than under 2 filters columns after the same running times. Hence, 3 filters columns, or a one-hour detention time are recommended to ensure efficient nitrate adsorption if nitrate is the nutrient of concern in wastewater, as the fairly large nitrate removal increase justifies the investment of an additional third column.

For nitrite, no significant improvement was observed from an increased contact time from 0.67 to 1h (increased number of columns from 2 to 3). Biochar generally showed a lower nitrite removal capacity compared to its reduction of other nutrient parameters. This may be due to the low influent nitrite concentration available to be adsorbed, as well as due to the competition of sorption sites. In this study, real wastewater was utilised rather than synthetic stock solutions. This was to increase the experiment's validity and more accurately reflect the biochars' nutrient removal capacity within real-life applications. As multiple rather than singular nutrients were contained in the influent, different nutrients would compete for biochar's adsorption sites. This competition between nutrient ions may have hindered the corncob biochar's adsorption of nitrite. Hence, nitrite may not be as strongly adsorbed as if it was the only nutrient found within synthetic water samples commonly used in past studies, that have not been able to stimulate real-life conditions.

III.3. Effect of running time on nutrient removal

The effect of different running times on bamboo biochar's removal of nutrients is presented in Table 2.

Table 2. Removal amount and removal efficiency of nutrients by bamboo biochar after different running times by 3 filter columns (corresponding to 1 hour detention time, *Influent pH: 8.70-9.17; phosphate: 1.42-4.40 mg/L; ammonium: 14.3-24.9 mg/L; nitrate: 15.6-22.6 mg/L; nitrite: 0.38-0.54 mg/L)*

Running time (hours)	**PO_4^{3-}**		**NH_4^+**		**NO_3^-**		**NO_2^-**	
	Removal amount (mg)	**Removal efficiency (%)**	**Removal amount (mg)**	**Removal efficiency (%)**	**Removal amount (mg)**	**Removal efficiency (%)**	**Removal amount (mg)**	**Removal efficiency (%)**
12	0.28	36.8	4.66	55.4	4.40	42.6	0.04	22.2
24	0.52	36.1	9.34	55.6	8.64	40.8	0.12	27.3
36	0.98	37.7	12.50	52.3	11.89	41.1	0.15	24.2
48	2.17	46.1	13.94	42.7	14.96	40.3	0.19	22.1
60	3.28	53.2	15.90	35.7	17.24	38.6	0.22	20.2
72	4.23	55.6	17.13	30.3	18.13	34.8	0.23	17.4

A longer running time from 0 to 72 hours had a notable increase in phosphate adsorbed by bamboo biochar, with the majority of phosphate adsorption being within the later stages of running time. 3.25 mg (75%) of the total 4.23 mg of phosphate removed was between hours 36-72, with phosphate removal increasing gradually from 37.7% to 55.6% at the end of the 72 hours. The greater amount of phosphate adsorbed (in mg) later in the trial suggests that competitive adsorption for adsorption sites is occurring between phosphate and ammonium compounds, with ammonium being favourably adsorbed before phosphate compounds. This hypothesis is based on biochar's ammonium adosoprtion in mg being highest within the first 24 hours (9.34 mg) whilst phosphate removal by bamboo biochar being at its lowest then (0.52 mg). Conversely, bamboo biochar's highest phosphate removal occurred when its ammonium removal was at a lower rate.

Similar to the trend observed for ammonium, bamboo biochar's nitrate removal was at its highest in the early stages of running time (0-36 hours), in which its removal efficiency was between 40.8-42.6%. Following this, its removal efficiency was still substantial, however lowered, decreasing to 34.8-40.3%. Hence, it is recommended that 36 hours of wastewater detention time is most suitable and effective.

Likewise to all the other trialed nutrient parameters (apart from phosphate), the 1st 36 hours had the most efficient rate of nutrient removal for nitrite, with its removal efficiency within this time frame being between 22.2-27.3%. Removal amount of nitrite in terms of mg of nitrite adsorbed by bamboo biochar did increase with an increased running time following this, with a further 0.08 mg nitrite removed from 36-72 hours of running time. However, the removal efficiency was still less than within the first 36 hours.

III.4. Effect of biochar on plant growth

The effect of the addition of exhausted/used biochars as a fertiliser material on plant growth and health is presented in Figures 2 to 4.

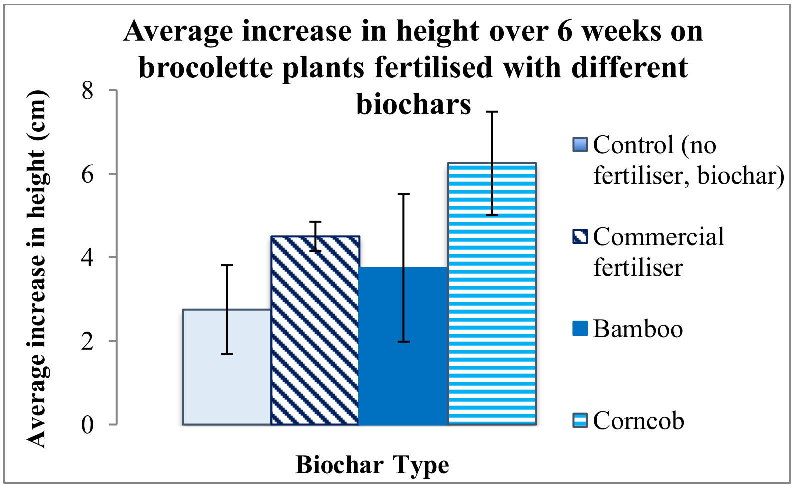

Figure 2. Average increase in height over six weeks of brocolette plants fertilised with different biochars and commercial fertilizer

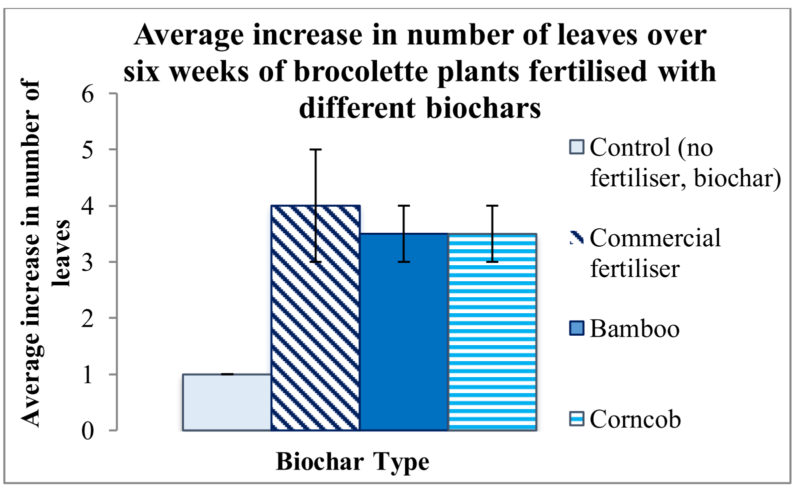

Figure 3- Average increase in number of leaves over six weeks of brocolette plants fertilised with different biochars and commercial fertilizer

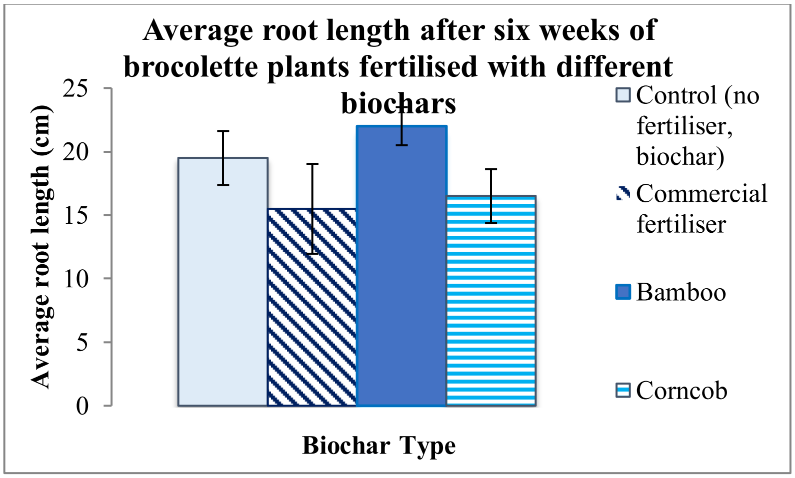

Figure 4. Average root length after six weeks of brocolette plants fertilised with different biochars and commercial fertilizer

Results from the plant tests demonstrate that both the bamboo and corncob biochars are similar in their fertiliser capacity, and are both highly suitable as a fertiliser material. This is based on corncob biochar fertiliser increasing the height of brocolette plants by 6.25 cm on average over the 6 weeks, 38% greater than the average height increase of plants fertilised with the commercial fertiliser. Similarly, bamboo biochar fertilised plants also displayed a comparable growth in height to plants fertilised by commercial fertiliser. The growth rate between bamboo biochar and commercially fertilised plants differed by only 16% on average, with bamboo biochar fertilised plants growing at a 37% greater rate than control plants.

Regarding the leaf health of plants under different fertiliser conditions, the bamboo biochar and corncob biochar both increased the brocolette plant leaves by 3-4 leaves, corresponding to a 70-78% increase in number of leaves (from an initial 4-5 leaves). Bamboo and corncob fertiliser also both exceeded the commercial fertiliser's capacity in terms of aiding root health. Plants fertilised by these biochar materials displayed a more extensive and longer root system after six weeks than commercially fertilised plants (by 1-6.5 cm).

Thus, the above results show that in terms of improving soil quality and plant growth, both bamboo and corncob biochar demonstrate comparable or stronger fertiliser capacity to commercial fertilizer. This hence renders them viable for agricultural application as an alternative to costly commercial fertilisers.

IV. DISCUSSION

IV.1. Optimal biochar material: ***Bamboo***

Bamboo biochar removed 2-24% more nutrients than the other trialed materials (Figure 1, Tables 1 and 2). In addition, bamboo biochar adsorbed nutrients consistently better than corncob biochar in the long term study, removing 76% more total nutrient content after 36 hours under 3 filter columns (Tables 1 and 2). This may be due to bamboo biochar having a higher specific surface area than the other plant wastes and hence more available adsorption sites (surface area 2-3 times higher than corncob biochar, in which bamboo biochar's specific surface area was 2.27-91 m^2/g compared to 0.96 m^2/g of corncob biochar produced at the same temperatures, Vu et al., 2017). In addition, bamboo as a biochar material is attractive on a practical basis, as it is globally accessible and a fast-growing crop. Unlike most woods, its harvest period is much shorter (3 years) and it can regenerate without replanting (Chen. 2017).

IV.2. Optimal detention time ***(1 hour)*** *and biochar amount (****under 7kg biochar/m^3 wastewater)***

Based on Table 1, a 1 hour detention time was most effective, removing 15% more nutrients than a 0.67 hour detention time, justifying the additional detention time. As each filter column contained 3.50 g of material that treated 1 L/day, less than 7kg of biochar can treat 1m^3 of wastewater to meet Australian effluent standards (ARMCANZ, 1997).

IV.3. Choice of running time ***(36 hours or if phosphate levels are of concern: 72 hours)***

The first 36 hours is the most time-efficient period to apply bamboo biochar. 56% more nutrients were removed in the first 36 hours than in the later 36 hours, indicating a gradual decrease in available adsorption sites. However, if phosphate levels are concerning, running time should be extended to at least 72 hours due to competitive adsorption. Bamboo biochar's sites were favourable to nitrogen compounds in early running times, whilst favourable to phosphate in later stages (Table 2). The most time efficient period of phosphate removal was in the last 24 hours trialed, during which 38% of phosphate removal occurred.

In addition, during column tests, white particles were formed inside the columns and after 72 hours of operation, the first column became blocked. The phenomenon can be explained based on how the urine containing mostly amorphous phosphates due to the influent conditions being alkaline (pH 8.7-9.17). This condition resulted in a white precipitate of phosphate being formed (Bradley, 1982). In practical applications of biochar, to address this precipitate, the exhausted bamboo biochar filters can be replaced and reused as a fertiliser instead of backwashing the filter column, further enhancing the biochar's productivity.

IV.4. Reuse as a fertiliser

Following use as filter for wastewater, bamboo biochar is proposed to be recycled as a fertiliser for crops and is deemed a viable alternative to the trialled commercial fertilizer, improving plant growth at a comparable rate. Plants bamboo biochar fertilized showed a 37% greater height increase (Figure 2) than controlled plants, with the growth in height between commercially and bamboo biochar fertilised plants only differing by 16%. The increase in number of leaves on plants bamboo-biochar enriched was also double that of plants unfertilised. Additionally, bamboo biochar fertilized plants had the healthiest root systems, their average root length being 41% more than plants commercially fertilised. Thus, both used biochars are viable supplements or alternatives to commercial fertilizer.

It is interesting to note that despite the bamboo biochar containing more nutrient content (39.72 mg of ammonium, nitrate, nitrite, phosphate/10.50 g) than corncob biochar (24.49 mg of ammonium, nitrate, nitrite, phosphate/10.50 g), corncob biochar aided plant growth more. This may indicate specific chemical characteristics of corncob biochar, such as its high water holding capacity (Piash, 2014) are also valuable factors contributing to its fertiliser performance. Further research into the specific surface chemistry of biochar is recommended to better understand the full reasons for biochar's effectiveness as a fertiliser, apart from its nutrient contributions to soil.

IV.5. Recommendations for practical applications of biochar

Biochar can be easily produced through a variety of methods, such as by using biochar gasifiers that also provide enough heat energy for household cooking during pyrolysis. In countries such as Vietnam, gasifiers are available for $45-65 USD depending on size, with 12 volts of energy being required to power one 60 cm household gasifier that can produce 1-2 kg of biochar for each period of use (Olivier, 2017). This low amount of electrical energy required and the heat energy produced being able to be used for household purposes (cooking) increases the viability and accessibility of biochar production use in smaller farms, such as within rural areas and developing nations. For applications of biochar on large farms, commercial ovens may be suitable for use.

Photo 7: a biochar gasifier in which the heat energy produced upon pyrolysis can be used for household cooking purposes (components include a fan, crown, reactor body,

V. CONCLUSION

V.1. Outline for DECENTRALISED BAMBOO BIOCHAR FILTER SYSTEMS

- Filtration rate: 5.5 m^3/m^2/day, Amount: less than 7kg of biochar/m^3 of wastewater
- Detention time of wastewater in filter column/s: 1 hour
- Running time: 36 hours (or over 72 hours if phosphate levels are concerning)

This novel model presents the agricultural industry an economic and sustainable method to minimize its environmental impact and the risk of harmful eutrophication A significant 45.6% of wastewater nutrients in wastewater were removed through this model's use under a 36 hour running time. This model achieved a:

- 52% ammonium, 38% phosphate, 41% nitrate and 24% nitrite removal
- Removal of total nitrogen to under 20mg/L and phosphorus to under 2mg/L, meeting Australia effluent guidelines (ARMCANZ, 1997)

V.2. Benefits and potentials offered to the agricultural industry and environment of the model

1) A minimisation of environmental pollution, at a level comparable to current bioadsorbents

Biochar recycling polluting agricultural wastes and filtering animal wastewater may help reduce the impact of two severe global environmental problems: water pollution and air pollution, caused when these waste products are burnt in developing nations (Vu et al, 2017). The nutrient content removed by bamboo is high, comparable to current bioadsorbents. It should be noted that the adsorption capacity of the following bioadsorbents was calculated in batch studies using synthetic wastewater that contained only one type of nutrient, hence allowing for a higher rate of removal. This contrasts to this study replicating realistic wastewater nutrient levels with urine and competitive adsorption, more accurately reflecting real-world results. This study has thus maximised the efficiency of biochar bioadsorbents so that even with this real-life competitive adsorption occurring, the biochar's nutrient adsorption capacity is of a high standard.

- Maximum ammonium removal by bamboo biochar was 1.63 mg/g, comparable with other ammonium biosorbents such as rice husk and slag, which remove up to 2.10 mg/g and 3.1 mg/g (Zhu, 2012).
- Maximum phosphate removal by bamboo biochar was 0.40mg/g, competitive with adsorption methods used presently including: limestone (0.3 mg/g - Hussain et al., 2011), opoka (0.1 mg/g - Johansson, 1999), dolomite (1 mg/g - Karaca et al., 2006).
- Maximum nitrate removal 1.73 mg/g. Similar to a range of current adsorption methods, eg halloysite (0.54 mg/g), mustard straw (1.30 mg/g) (Bhatnagar, 2011; Tezuka, 2004).

2) Practical and cost-effective wastewater treatment method, with financial benefits

Biochar filters do not require an extensive amount of time (detention time 1 hour) to remove high levels of nutrients to meet Australian guidelines. Additionally, this model is within simple decentralised filter systems and does not require skilled operators, with this biochar model being accessible for use by farmers. Biochar's multiple purposes as both filter and fertilizer also increase this model's accessibility and practicality worldwide, especially in developing nations where present chemical and biological treatment methods are economically unattainable and water pollution is prevalent.

Moreover, economic benefits of this model derive from how it transfers the nutrients biochar has adsorbed from wastewater into soil, resulting in biochar having a strong potential to act as an alternative to commercial fertilisers. This can help to reduce the costs of commercial fertilisers, one of the largest single variable costs for Australian grain producers (accounting for 20-25% of variable costs, IPNI, 2013).

3) Sustainable

As biochar is produced from agricultural wastes in abundance and that would otherwise pollute the environment, it is fairly cost-effective as its components are readily available (average price to produce 1 kg of biochar about $1 USD) (Porter, 2014). The model's sustainability aspect is also further enhanced due to how the biochar is returned to the soil, aiding the growth of plants whose wastes later become biochar. This ensures the model is a self-sustaining cycle, especially if used on farms with both livestock and crop operations.

VI. FURTHER STUDIES

Further experimentation will be conducted at a farm in Victoria, Australia (supported by Food and Farm Life Victoria, Australia). The model will be trialed on a larger scale with more variables tested, to improve the model and further ascertain the optimum filtration conditions. The following additional tests will be conducted:

- Biochar will be trialed under different flow rates, detention times, and with different chemical modifications applied
- Exhausted biochar fertiliser will be trialed with different plants

VII. BIBLIOGRAPHY

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