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Biochar: a Sustainable Approach of Green Waste Management in Agricultural Practices under Controlled Microclimate

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Cucumber waste from the greenhouse is a nutrient and high cellulose-rich biomass that could potentially be used to produce biochar as a valuable resource. Therefore, this study was conducted to produce biochar from cucumber green waste collected from a greenhouse in Qatar. The green waste was cut into small pieces (5 to 10 cm) for oven drying at a temperature of 105 °C for 24 h to remove moisture and was then pyrolysed in a muffle furnace at three temperatures of 300, 350, and 550 °C with a heating rate of 5 °C min^{-1} and residence time of 30 min. This study focuses on the nutrient analysis of biochar, including yield, pH and electrical conductivity (EC). Additionally, a small-scale pot test with cucumber plants applied 0% (control) and 2% biochar to a coco-peat substrate under a controlled microclimate with an enriched CO_2 environment of 1000 ppm in a climate chamber. The pots were irrigated with a nutrient rich solution. Results demonstrate that the biochar produced with a higher pyrolysis temperature has a higher C content of 71%, pH of 10.59 and EC of 12.93 mS cm^{-1} with more aluminium, copper, and manganese. The lower pyrolysis temperature biochar possessed a higher N content of 3% and improved biochar yield of 48% with maximum potassium and iron concentrations. The application of 2% biochar was found to be linked to a maximum increase of 39% in plant height, 32% in leaf area, 3% in chlorophyll content, and a reduction of 71% in water loss by drainage as compared to the control. Moreover, both low and high temperature biochar applications display good plant growth by reducing water loss, while nutrient loss was more significant in the 2% biochar application at all three temperature conditions than the control. This study demonstrates that a lower fraction of biochar application could be beneficial for sustainable agricultural practices to reduce water drainage and nutrient supply.
Keywords: Cucumber; Green waste; Biochar; Plant growth; Water loss; Nutrients leaching

1. Introduction

The Green Revolution in developing countries has made major contributions in the Food and Agricultural Organization (FAO) to transform global agriculture to increase high-yield crop varieties. The rapid growth and higher crop production has also generated higher green wastes containing high starch and cellulose content (FAO, 2017). Large quantities of green waste from the agricultural sector are being disposed of in landfills which pose severe issues on the ecosystem and environment such as methane generation and bad odors (Abdel-Shafy et al., 2018). The composting of these wastes has been a much promoted option. However, only very small amounts of these products are currently being used in agriculture, e.g. only 4% of compost products is used in agriculture in New South Wales due to various market barriers including high transport costs (Chan et al. 2007). Moreover, the production of biogas and biofuel has not been the most profitable way to reutilise these wastes. Biochar gained attention over the last two decades due to its potential impact on C-sequestration, soil fertility, increasing nutrients uptake and improving soil structure (Pradhan et al., 2020). Greenhouse cucumbers are agriculturally profitable, but such intensive cultivation causes environmental issues due to the enormous volume of post-harvest refuse. According to a survey in France, greenhouse cucumber crops produce a tremendous amount of plant waste, around 170 t ha^{-1} of greenhouse footprint in the form of shoots, stems and

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leaves (Oleszek et al., 2016). Thus, biochar production from green waste could be a sustainable approach for agricultural practices and provide an opportunity for sustainable waste disposal. Moreover, its integration back into agricultural systems promotes a circular economy. Several studies investigated biochar production from various biomass. However, only a few studies encompassed biochar production from green waste biomass and its application in agricultural systems (Dunlop et al., 2015). Therefore, this study aims at producing biochar from cucumber green waste at different pyrolysis temperatures, applying it to a soilless substrate for the cultivation of cucumber crops, and evaluating its effect on plant growth. This work also aims at analysing the impact of biochar pyrolysis temperature on property changes of biochar, plant growth, water loss by drainage and nutrients leaching.

2. Materials and methods

2.1 Biochar production

Green waste biomass was collected from an agricultural greenhouse in Qatar after harvesting cucumber crops. The biomass was segregated and cut into a size of 5 to 10 cm before drying at a temperature of 105°C for a duration of 24 h. The dried green waste was further crushed manually by hand and pyrolysed at different operating temperatures of 300 °C, 350 °C, and 550 °C with a heating rate of 5 °C min^{-1} for 30 min under nitrogen (N_2) gas supply of 1 mL min^{-1} in a muffle furnace (Lindberg Blue M-3504, Thermo Scientific). Approximately 200 g of dried biomass was used to produce biochar. After biochar production the yield of biochar was calculated following Eq(1).

$$Yield\ (\%) = \frac{m_{biochar}\ (g)}{m_{biomass}\ (g)} \times 100 \tag{1}$$

where $m_{biochar}$ is the mass of biochar after pyrolysis and $m_{biomass}$ is the dried mass of biomass before pyrolysis.

The produced biochar at the three different temperature conditions were grinded and sieved to a particle size less than 125 µm using a shaking sieve (Haver EML Digital Plus, Haver and Boeker). A detailed methodology of biochar production, characterisation and application to the substrate for plant growth is illustrated in Figure 1.

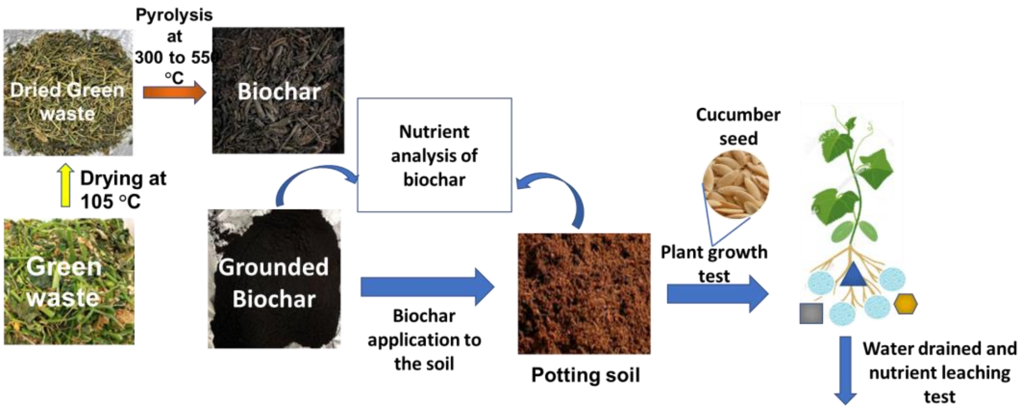

Figure 1: A detailed methodology of green waste biochar application in an agricultural practice.

2.2 Biochar analysis and characterisation

The pH and electrical conductivity (EC) of biomass and biochar were determined using a pH meter (Orion Star A121, ThermoScientific) and a conductivity meter (A329, ThermoScientific). For this, the grinded and sieved biomass and biochar (particle size ≤125 µm) were mixed with distilled water with a ratio of 1:5 and were put in a shaker at 150 rpm for 1 h. A combustion-type elemental analyser (EA 3000, Eurovector) was used to determine carbon (C), nitrogen (N), and hydrogen (H) content of the biosolid and biochar. The presence of nutrients in biomass and biochar was conducted by inductively coupled plasma optical emission spectrometry (ICP-OES) using an Agilent 5110 ICP-OES that enables synchronous radial and axial measurements. Before analysis, 500 mg of sample was digested with 8 mL nitric acid and 2 mL hydrogen peroxide with a microwave digestion system (Ethos UP, Milestone). After digestion, samples were diluted with deionised water and filtered with 0.45 µm filter paper.

Pot test

Cucumbers *(Cucumis sativus)* with the variation Beautysun RZ mini cucumber were used in this experiment. Seeds were introduced in a soil containing 95% potting soil and 5% perlite mix. The pots were kept in an climate chamber (CLIMACELL EVO, MMM Group) with a set temperature of 30 °C, relative humidity of 90%, and with no lighting for the first two days as per the greenhouse germination conditions. After getting visual seedlings, the temperature was then lowered to 26 °C and light was introduced for the rest 13 days of germination. A volume of 50 mL of water was fed every alternative day during the germination stage. After day 13, the seedlings were transferred into pots by filling with biochar amended coco-peat substrate. Six seedlings were grown with duplicates for each biochar type by applying 0% and 2% biochar produced at three temperature conditions (300, 350, and 550 °C) to observe the impact of biochar on cucumber (*Cucurbitaceae*) plant growth. According to the greenhouse conditions, dry coco-peat substrate was initially washed, soaked in water, and allowed to drain for a period of two days before mixing with biochar. The cucumber plant growth test was conducted inside the climate chamber at a temperature of 26 °C and 80% relative humidity for 24 h. Visible lighting of 10 klux and CO_2 concentrations of 1000 ppm were introduced for 12 h corresponding to daytime conditions. In nighttime, the microclimate conditions were set to 1.8 klux of visible light and 400 ppm of CO_2 levels for the next 12 hours equivalent to night time conditions. The whole process was sustained for the complete analysis of the plant growth study. After thirteen days, the plants were irrigated with nutrients by preparing a solution reported in Table 1.

Table 1: A complete recipe of nutrients used for irrigation.

Solution 1	**Amounts**
Water (L)	200
YaraTera Calcinit (kg)	23
Total nitrogen N (%)	15.5
Calcium (CaO) (%)	26.5
Iron Fe DTPA (6%) kg	0.25
Solution 2	**Amounts**
Water (L)	200
YaraTera Kristalon Brown (kg)	27
Nitrate NO_3-N (%)	3
P_2O_5 (%)	11
K_2O (%)	38
MgO (%)	4
SO_3 (%)	5
B (%)	0.025
Ca (%)	0.01
Fe (%)	0.07
Mn (%)	0.04
Mo (%)	0.004
Zn (%)	0.025
YaraTera Krista MgS (kg)	5
MgO (%)	16
SO_3 (%)	32.5
Manganese EDTA (kg)	2

The two solutions were diluted with tap water at a ratio of 1:1 to maintain a pH of 5.5 to 6.5 and an EC of 2.6 mS cm^{-1}. Plants were irrigated with 100-150 mL day^{-1} of nutrients solution every day during the daytime. The plant growth test was conducted by measuring plant height, number of leaves, leaf area, and chlorophyll content throughout the growing period. Leaf area (LA) was calculated by measuring leaf length (L) and leaf width (W) by following the leaf area regression model expressed in Eq(2) (Cho et al., 2007). At the same time the volume of water drained and nutrients leached by drained water was measured in all the pots.

$$\mathrm{LA} = -22.13 + 14.177\mathrm{W} + 0.3613\mathrm{L}^2 + 0.1838\mathrm{W}^2 \quad (2)$$

3. Results and discussion

3.1 Biomass and biochar properties

The yield of biochar is highly influenced by pyrolysis temperature (Table 2). With increasing temperature, the yield of biochar decreases, while a very small variation in yield was noticed between biochar at 300° C and 350° C. At higher temperature of 550° C, a reduction of 5% yield was noticed in comparison to 350° C due to the higher conversion of volatile matters to carbonaceous compounds. Therefore, the pH and EC of biochar increases with increasing pyrolysis temperature and was found maximum for biochar at 550° C. The application of biochar with a high pH values of 7.6 to 9.3, high EC values more than 4.6 mS cm−1 and high carbon values, more than 55%, reveal good plant growth and maximum water retention capacity compared to the control (0% biochar). The concentration of aluminium (Al), copper (Cu) and manganese (Mn) in biochar increased by increasing pyrolysis temperature except for potassium (K) and iron (Fe), which were observed at maximum at a temperature of 300 °C. The concentration of zinc (Zn) was approximately similar in the three types of biochar. These nutrients are required for plant growth to develop leaf chlorophyll content, root and shoot, as well as increase photosynthesis and water retention capacity (Raza et al., 2021).

Table 2: Various physico-chemical and nutrient properties of biomass and biochar properties.

Sample/ Test	Biomass	Biochar 300° C	Biochar 350° C	Biochar 550° C
Yield	-	48%	47%	42%
C (%)	30.19±2.31	43.48±3.73	60.38±1.98	70.72±2.62
N (%)	3.00±0.40	3.02±0.28	2.80±0.58	1.33±0.19
H (%)	4.24±0.24	1.88±0.21	1.44±0.09	1.38±0.18
pH	8.96±0.06	10.79±0.05	11.03±0.03	10.59±0.16
Electrical conductivity EC (mS cm^{-1})	3.37±0.76	19.15±0.60	20.57±0.25	12.93±0.67
Nutrients (mg g^{-1})				
Aluminium (Al)	0.0132	0.0164	0.0165	0.0176
Copper (Cu)	0.0052	0.0059	0.0044	0.0071
Potassium (K)	0.0607	0.2074	0.1904	0.1730
Manganese (Mn)	0.0030	0.0032	0.0029	0.0042
Zinc (Zn)	0.0012	0.0019	0.0020	0.0020
Iron (Fe)	0.0133	0.0223	0.0174	0.0198

3.2 Plant growth test

The impact of 0% (control) and 2% biochar application (produced at three different temperatures) is shown in Figure 3. Maximum cucumber plant height, leaf area and chlorophyll content were noticed with 2% biochar produced at 550 °C. Compared to the control condition, 2% biochar application produced at 550 °C increased plant height by 39% and leaf area by 32% with a slight (3%) increase of chlorophyll content.

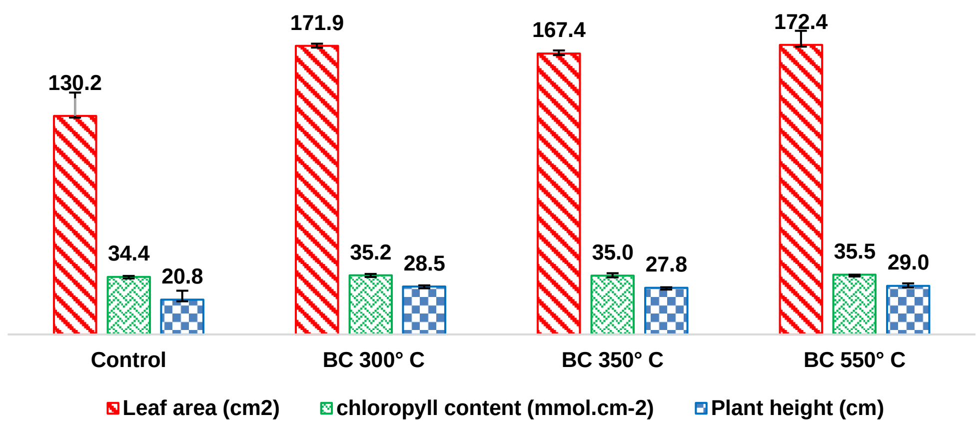

Figure 1: Impact of 0% (control) and 2% biochar application on plant height, leaf area, leaf chlorophyll content after thirty days of pot test.

Application of 2% biochar produced at higher temperature (550 °C) showed a competitive growth of plant height and leaf area. At the same time a slight increase of leaf area and chlorophyll content was noticed in pots with biochar produced at 550 °C in comparison to biochar at 300 °C and 350 °C respectively. The increase in chlorophyll content in the 2% biochar at 550 °C is due to the higher concentration of Fe and Zn (Table 2). Fe and Zn are the two major nutrients that improve leaf structure and chlorophyll content (Raza et al., 2021). With good plant growth, a 2% biochar application rate at three temperature conditions also demonstrates a reduction of water drainage compared to the control (Figure 4). Application of 2% biochar at 550 °C could be able to reduce water loss by drainage by 71% compared to the control condition, while biochar produced at lower pyrolysis temperature could reduce water drained by more than 50% than the control condition.

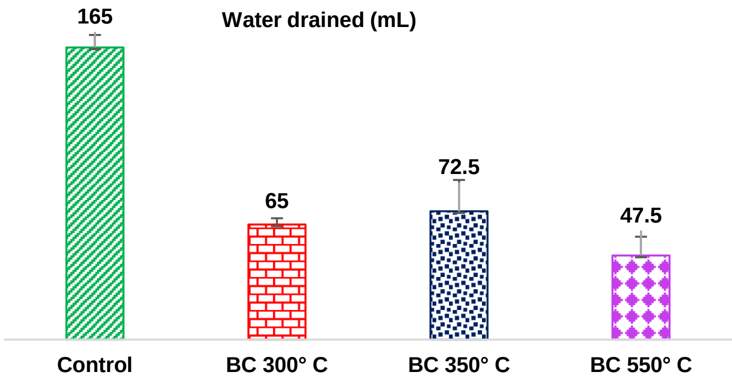

Figure 2: Impact of 0% (control) and 2% biochar application on drained water (mL) after thirty-four days of irrigation. BC: biochar

However, the leaching of nutrients from 2% biochar pots was comparatively more than the control condition (Table 3). This is due to the oversupply of nutrients solution to the biochar amended substrate as biochar has more nutrients than the control condition. Therefore, this study demonstrates that biochar amended substrate in greenhouse agricultural conditions requires a lesser quantity of nutrients for good plant growth, which reduces fertiliser cost and water supply-demand.

Table 3: Impact of biochar application on nutrients leaching from the nutrients reach irrigated water.

Drained water	**Control**	**Biochar 300° C**	**Biochar 350° C**	**Biochar 550° C**
Nutrients (mg g^{-1})				
Aluminium (Al)	0	0	0	0
Copper (Cu)	0.0002	0.0005	0.0002	0.0002
Potassium (K)	0.0259	0.0923	0.0488	0.0587
Manganese (Mn)	0	0	0	0
Zinc (Zn)	0.0003	0.0014	0.0002	0.0004
Barium (Ba)	0.000100	0.0003	0.0001	0.0001

4. Conclusions

This work demonstrates the application of 2% green waste biochar is a sustainable amendment for agricultural practices. The application effectively builds climate-resilient agricultural systems by improving plant growth and mitigating water loss by drainage with lesser nutrient requirements. This study proved the 2% biochar produced at lower and higher pyrolysis temperature conditions has different properties but are all efficient for cucumber crop cultivation in greenhouse controlled microclimate condition. The combination of nutrient-rich solution and biochar amender improved the plant growth with maximum increase of 39% in plant height, 32% in leaf area, 3% in chlorophyll content, along with a reduction of 71% in water loss by drainage as compared to the control. However, more nutrients supply led to more nutrients leaching from biochar amended substrate, which suggests that the biochar application is efficient to reduce the use of nutrient rich fertilisers and their associated costs. Based on the outcomes, there is an impetus to further investigate the application of applying green waste biochar to other plant growth tests in a large-scale greenhouse setting.

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