The application of water hyacinth biochar as the soil conditioner for vegetable planting in greenhouses with direct air capture CO_2 enrichment: a comparative study

Junye Wu[1,2,4], Yiying Wang[1,2], Guiying Lin[1,2], Lifeng Li[1,2], Chi-Hwa Wang[1,3], and Tianshu Ge[4]

[1] NUS Environmental Research Institute, National University of Singapore, Singapore 138602, Singapore
[2] Energy and Environmental Sustainability Solutions for Megacities (E2S2), Campus for Research Excellence and Technological Enterprise (CREATE), 138602, Singapore
[3] Department of Chemical and Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117585, Singapore
[4] Research Center of Solar Power & Refrigeration, Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, 200240, China
Keywords: biochar, soil conditioner, vegetable production, carbon dioxide, direct air capture
Presenting author email: e0974106@u.nus.edu

Due to land scarcity and high population density, modern cities face significant challenges in achieving food self-sufficiency and managing solid waste.(Chikanda et al., 2017; Ferronato et al., 2017) To address these issues, urban agriculture and sustainable waste disposal strategies are becoming attractive solutions to improve food quality and solid waste management in cities. Biomass gasification produces biochar as a by-product while converting solid waste into energy, so it is considered as an effective means of sustainable development. Biochar can not only contribute to greenhouse gas (GHG) emission reduction by altering the pathway of natural carbon cycle,(He et al., 2021) but also can be used as soil conditioner to enhance food output.(Arora et al., 2021) Water hyacinth is a promising candidate for biomass feedstock due to its potential in phytoremediation.(He et al., 2022) It has a high carbon content (33-47% of dry matter) and calorific value (13-19 MJ/kg), so gasification of water hyacinth is a suitable thermochemical process for bioenergy and biochar production.(Hu et al., 2015) However, studies on water hyacinth gasification are still very limited, especially for biochar applications as the soil conditioner.

Since CO_2 is the raw material for photosynthesis, the CO_2 enrichment during vegetable planting has been demonstrated to enhance crop yields.(M.Mortensen, 1987) Controlled environment agriculture, whose representative solution is the greenhouse, is recognized as an effective strategy to boost vegetable production. In greenhouses, the CO_2 concentration is released and kept at a certain concentration. Conventional method for CO_2 enrichment is adding organic matter bags or fermenting buckets that release CO_2 into a greenhouse. (Hao et al., 2020) These materials lose effectiveness over time and the amount of CO_2 delivered cannot be regulated. The combustion of hydrocarbon fuels is also utilized to generate CO_2.(Zhang et al., 2020; Zhang et al., 2022) Nevertheless, combustion without adequate oxygen may produce impurities that are harmful to plants. Seeking economic, environmental-friendly, and effective CO_2 enrichment strategy is imperative for further development of agriculture. In greenhouses, LED lighting can be used as an alternative to sunlight cultivation. This strategy makes the lighting time controllable in an artificial way, and it make it possible to transfer the plant indoors as cultivation without relying on the influence of natural weather. Therefore, LED lighting is considered to be an effective strategy for vegetable production enhancement.(Tan et al., 2020)

In order to achieve solid waste management and vegetable production improvement, this paper built an integrated greenhouse system (Figure 1) and studies the effects of multiple factors on plant growth, including the incorporation of biochar, the CO_2 enrichment, and the application of LED light irradiation. Two common edible vegetables, choy sum (Brassica rapa var. parachinensis) and pok choi (Brassica rapa subsp. chinensis), were selected for planting. The water hyacinth biochar was used as soil conditioner, and four mass ratios of biochar (0 wt.%, 4.0 wt.%, 7.4 wt.%, and 11.4 wt%) were set as potting substrates. Each biochar mass ratio had ten replicants. Four cultivation areas, marked as section A (open air with ~415 ppm CO_2), section B (transparent room with 700 ppm CO_2 concentration), section C (transparent room with 1000 ppm CO_2), and section D (LED room with 700 ppm CO_2), were set to plant the two kinds of vegetables to investigate the effects of environmental conditions. The CO_2 in section B, C, and D were provided by a rotary CO_2 capture device that captures CO_2 from the air and feeds it into the greenhouse.

The experimental results show that direct air capture rotary adsorber could capture CO_2 from air and deliver it to greenhouses stably, and successfully maintained the CO_2 concentration in the greenhouse at 700-1000 ppm. Compared to that in the section A, the CO_2 enrichments in section B and C facilitated vegetable production by 5~20%, while the 700 ppm CO_2 exhibited larger promotion effects. Compared to cultivation with natural sunlight, the combination of LED lights and CO_2 enrichment increased the time and efficiency of photosynthesis, and thus significantly increased vegetable yields by ~30%. With the biochar weight ratio in the potting substrate increased, the alkalinity of the substrate increased and adjusted the pH of the soil. The incorporation of different ratio of biochar had obvious effects on plant growth, and the proportion of 7.4 wt.% demonstrated the most obvious promotion effect. The composition tests showed that there was neglectable heavy metals in the harvested vegetables, showing the safety of biochar applications. This study provides an optimized vegetable planting strategy, which proves to have positive economic and environmental benefits and great potential for promotion.

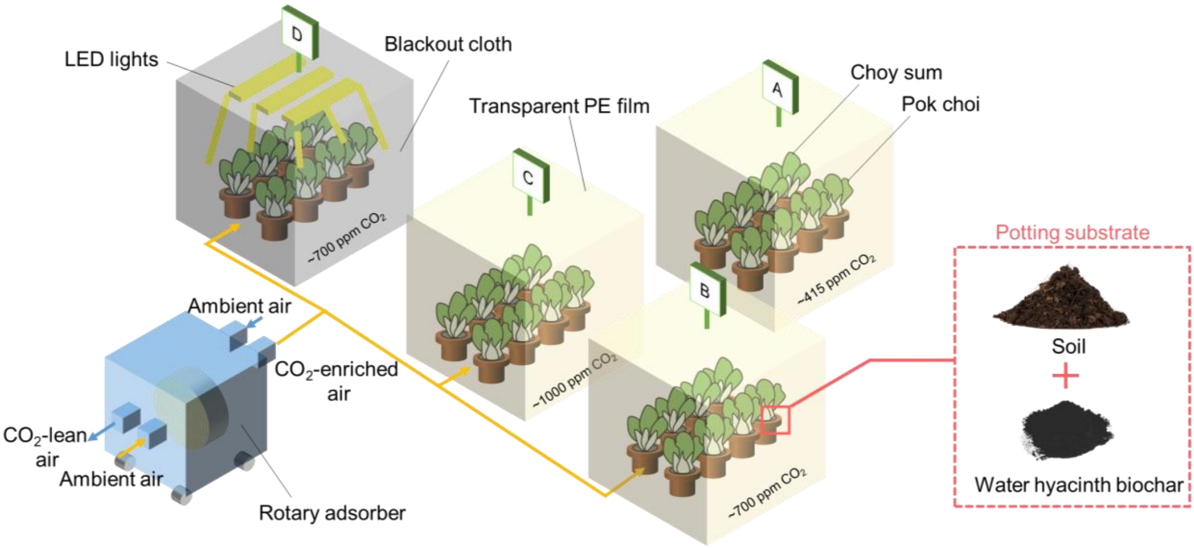

Figure 1 The overall layout of the integrated greenhouse system. Two vegetables (choy sum and pok choi) were planted in four sections using the mixture of soil and water hyacinth biochar as the potting substrate. The environmental conditions in four sections are open air (section A), 700 ppm CO_2 with sunlight (section B), 1000 ppm CO_2 with sunlight (section C), and 700 ppm CO_2 with LED lighting (section D). The CO_2 is supplied by a direct air capture rotary adsorber.

Acknowledgements
This research program is funded by the National Research Foundation (NRF), Prime Minister's Office, Singapore, under its Campus for Research Excellence and Technological Enterprise (CREATE) program (Grant No. A-0001032-01-00).

References

Arora, S., Jung, J., Liu, M., Li, X., Goel, A., Chen, J., Song, S., Anderson, C., Chen, D., Leong, K., Lim, S. H., Fong, S. L., Ghosh, S., Lin, A., Kua, H. W., Tan, H. T. W., Dai, Y., & Wang, C. H. (2021). Gasification biochar from horticultural waste: An exemplar of the circular economy in Singapore. *Sci Total Environ*, *781*, 146573. https://doi.org/10.1016/j.scitotenv.2021.146573

Chikanda, A., Crush, J., & Frayne, B. (2017). Migration and urbanization: Consequences for food security. *Food and nutrition security in Southern African cities*, 48-65.

Ferronato, N., Torretta, V., Ragazzi, M., & Rada, E. C. (2017). Waste mismanagement in developing countries: A case study of environmental contamination. *UPB Sci. Bull*, *79*(2), 185-196.

Hao, P.-F., Qiu, C.-W., Ding, G., Vincze, E., Zhang, G., Zhang, Y., & Wu, F. (2020). Agriculture organic wastes fermentation CO2 enrichment in greenhouse and the fermentation residues improve growth, yield and fruit quality in tomato. *Journal of Cleaner Production*, *275*. https://doi.org/10.1016/j.jclepro.2020.123885

He, X., Wang, C.-H., & Shoemaker, C. A. (2021). Multi-objective optimization of an integrated biomass waste fixed-bed gasification system for power and biochar co-production. *Computers & Chemical Engineering*, *154*, 107457. https://doi.org/https://doi.org/10.1016/j.compchemeng.2021.107457

He, X., Wang, Y., Tai, M. H., Lin, A., Owyong, S., Li, X., Leong, K., Yusof, M. L. M., Ghosh, S., & Wang, C.-H. (2022). Integrated applications of water hyacinth biochar: A circular economy case study. *Journal of Cleaner Production*, *378*. https://doi.org/10.1016/j.jclepro.2022.134621

Hu, Z., Ma, X., & Li, L. (2015). Optimal conditions for the catalytic and non-catalytic pyrolysis of water hyacinth. *Energy Conversion and Management*, *94*, 337-344. https://doi.org/10.1016/j.enconman.2015.01.087

M.Mortensen, L. (1987). Review: CO2 enrichment in greenhouses. Crop responses. *Scientia Horticulturae*, *33*(1-2), 1-25.

Tan, W. K., Goenadie, V., Lee, H. W., Liang, X., Loh, C. S., Ong, C. N., & Tan, H. T. W. (2020). Growth and glucosinolate profiles of a common Asian green leafy vegetable, Brassica rapa subsp. chinensis var. parachinensis (choy sum), under LED lighting. *Scientia Horticulturae*, *261*, 108922. https://doi.org/https://doi.org/10.1016/j.scienta.2019.108922

Zhang, Y., Yasutake, D., Hidaka, K., Kitano, M., & Okayasu, T. (2020). CFD analysis for evaluating and optimizing spatial distribution of CO2 concentration in a strawberry greenhouse under different CO2 enrichment methods. *Computers and Electronics in Agriculture*, *179*. https://doi.org/10.1016/j.compag.2020.105811

Zhang, Y., Yasutake, D., Hidaka, K., Okayasu, T., Kitano, M., & Hirota, T. (2022). Crop-localised CO2 enrichment improves the microclimate, photosynthetic distribution and energy utilisation efficiency in a greenhouse. *Journal of Cleaner Production*, *371*. https://doi.org/10.1016/j.jclepro.2022.133465