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Biochar: Its Role and Perspectives in Agriculture and Forestry Circular Economy in Taiwan[1]

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Nowadays, the old linear economy model, taking, making, and disposing, has been moved to a new paradigm called the circular economy[2]. The elements include regeneration, sharing, optimization, looping, virtualization, and exchanging[3]. For an agriculture and forestry circular economy, the loop pathway can be divided into raw materials, design, production remanufacturing, distribution, consumption (including using, reusing, and repairing), collection, and recycling[4]. The resource-efficiency[5] is a basis for sustainable growth in the agriculture and forestry circular economy. However, utilization of residual wastes will be a key for a full loop of the agriculture and forestry circular economy. To utilize the residual waste, energy conversion is normally a fast, easy and effective method. Now biochar produced from the agricultural and forestry residual waste could be an alternative way to close the loop.

According to the definition by International Biochar Initiative (IBI), biochar is a carbonized solid biomass production by carbonization of solid biomass feedstock[6]. Biochar can be used not only as solid fuels, but also as soil amendment materials with carbon sequestration. In agricultural applications, due to the porous structure and high specific surface area itself, biochar has a good adsorption effect on absorbing organic pollutants in the soil and reducing crop absorption of pollutants[7]. Mixed with the soil, biochar can also decrease the soil bulk density, increase the soil porosity, and improve aeration and water holding capacity (WHC) of soil[8,9]. It may be used as a refuge for colonizing fungi and bacteria[10]. Also in the chemical properties, biochar can effectively improve the soil cation exchange capacity (CEC), pH values[11], retention of nutrients needed by plants[12]. In addition, biochar can enhance the bio-available nutrients and root colonization ability by mycorrhizal fungi in the symbiosis environment

1 Financial supports of this work by the Taiwan Forestry Research Institute (Grant No. 106AS-18.2.2- FI-G3 and 107AS-18.2.2-FI-G1) are gratefully acknowledged.
2 Ellen MacArthur Foundation, Towards the Circular Economy, Vol. 1: An Economic and Business Rationale for an Accelerated Transition, Ellen MacArthur Foundation, Isle of Wight, UK (2012).
3 Ibid.
4 EIP-AGRI, 'Opportunities for Agriculture and Forestry in the Circular Economy' -Workshop Report, the European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI), Brussels, Belgium (2015).
5 Ibid.
6 International Biochar Initiative, https://www.biochar-international.org/, Retrieved on 28 July, 2018.
7 Yu, X. Y., Ying, G. G., Kookana, R. S., Reduced Plant Uptake of Pesticides with Biochar Additions to Soil. Chemosphere, 76: 665–671 (2009).
8 Chan, K. Y., van Zwieten, L., Meszaros, I., Downie, A., Joseph, S., Agronomic Values of Greenwaste Biochar as a Soil Amendment. Australian J. Soil Research, 45: 629-634 (2007).
9 Case, S. D. C., Mcnamara, N. P., Reay, D. S., Whitaker, J., The Effect of Biochar Addition on N_2O and CO_2 Emissions from a Sandy Loam Soil – The Role of Soil Aeration. Soil Biology & Biochemistry, 51: 125-134 (2011).
10 Warnock, D. D., Lehmann, J., Kuyper, T. W., Rilling, M. C., Mycorrhizal Responses to Biochar in Soil – Concepts and Mechanisms. Plant Soil, 300: 9-20 (2007).
11 Lehmann, J., Bio-energy in the Black. Front Ecol. Environ., 5: 381–387 (2007).
12 Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O`Neill, B., Skjemstad, J. O., Thies, J., Luizão, F. J., Petersen, J., Neves, E. G., Black Carbon Increases Cation Exchange Capacity in Soil. Soil Science Society of America Journal, 70: 1719-1730 (2006).

with mycorrhizal[13]. The previous study[14] shows that the pore diameter and specific surface area (SSA) of biochar dominate nutrient retention in the soil. The pore diameter increased with increasing the biochar preparation temperature. Smaller micropores (< 2 nm) and larger SSA can assist the soil in retaining and releasing nutrients for growing plants. However, when biochar is made at above 600oC, the micropores are too small to release nutrients for plants. Thus, the activated carbon cannot be employed as biochar, because it does not release the nutrients to the soil due to its extreme tiny pore. Based on an IBI's report[15], if the carbon sequestration is through biomass energy, the net carbon withdrawal from the atmosphere is 0%, i.e., the net CO2 emission is zero. If the biochar is mixed with the soil, net carbon withdrawal from atmosphere is about 20%. A research also confirmed that the climate-change mitigation potential of biochar is much more than that of direct combustion of the same biomass feedstock[16].

According to a market research report[17], the global biochar production was 395.3 kt approximately in 2018. It was estimated that the total value of output was US$ 1.3 billion. Currently the largest biochar market is in North America, following by Asia Pacific and China. However, the above biochar shown in this report was not only for soil amendment, but also for water treatment, etc. Now around 13 potential biochar markets emerged as shown in Table 1[18].

Table 1 The emerging potential biochar markets[19]

- Trees and Landscaping, Structural Soil
- Nurseries, peat moss industry
- Seed coating, prills and agglomerates
- Green roofs
- Urban farms and gardens
- Stormwater and water quality
- Bedding, kitty litter
- Food waste and food processors

Turf maintenance

- Traditional horticulture, hydroponics, poultry farms

Erosion control and soil remediation

- Specialized or strategic use in agriculture
- Forest re-vegetation

Source: Mile, T., Markets, Production, and Growth of the US Biochar Industry. Biochar: What Is the Future for Industrial Production and World Usage? ASA, CSA, & SSSA International Annual Meeting, California (2014).
Courtesy of Tom Mile.

In Taiwan, according to the latest statistics, except for the municipal wastes and general industrial wastes, the dry agriculture and forest solid residues were estimated at about 1,275,777 t/yr in 2011[20]. It would be a large resource for making biochar. In addition, producing and utilizing biochar can accelerate the formation of Taiwanese agriculture and forestry circular economy. Therefore, to boost

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13 Lehmann, J., da Silva Jr., J. P., Steiner, C., Nehls, T., Zech, W., Glaser, B., Nutrient Availability and Leaching in an Archaeological Anthrosol and a Ferralsol of the Central Amazon Basin: Fertilizer, Manure and Charcoal Amendments. Plant and Soil, 249: 343-357 (2003).

14 Wu, K.-T. , L. W. Yu, Y. H. Yen, C. J. Tsai, C. T. Chen, C. Y. Chang and R. Y. Chein, Effects of Biochar from Torrefaction and Carbonization of Woody Biomass on Plant Growth. The 4th Asian Conference on Innovative Energy & Environmental Chemical Engineering (IEEChE-ASCON 2014), Yeosu, Korea (2014).

15 Supra note 5.

16 Woolf, D., J. E. Amonette, F. Alayne Street-Perrott, J. Lehmann and S. Joseph, Sustainable Biochar to Mitigate Global Climate Change. Nature Communications, DOI: 10.1038/ncomms1053 (2010).

17 Grand View Research, Inc., Biochar Market Size, Share & Trends Analysis Report by Technology (Gasification, Pyrolysis), by Application (Agriculture (Farming, Livestock), by Region, and Segment Forecasts, 2019 – 2025 (2019).

18 Mile, T., Markets, Production, and Growth of the US Biochar Industry. Biochar: What Is the Future for Industrial Production and World Usage? ASA, CSA, & SSSA International Annual Meeting, California (2014).

19 Ibid.

20 Chyang, C. S., Evaluation of Bioresource Information for Decentralized Bioenergy and Establishment of Pretreatment, Environmental Protection Administration, Taipei, Taiwan (2011). (*in Chinese*)

biochar application in Taiwan, recently, a Biochar Flagship Project was proposed by the Council of Agriculture called "Industrial Innovation on Agricultural Resource Recycling and Agricultural / Energy Co-Construction Flagship Project". The total budget was around US$ 12 million (2017-2020) for 20 projects at sub-project - Pillar II: Zero Waste Agriculture: Innovation Biochar Technology and New Industry Model. Pillar II consists of four tasks including Task 1: Biochar Feedstock Supply and Recycling System, Task 2: Advanced Biochar Production Technology and Integration, Task 3: Value-Added and Innovative Application of Biochar Products and Task 4: Biochar Management and End-Use Benefits[21].

Currently, most biochar in the world was by-product from biomass pyrolysis or gasification plants. For example, in the US, biochar was mainly from industrial char residuals including combustion and gasification systems (>20,000 cubic yards/year), and from co-products of activated carbon (<4,000 cubic yards/year)[22]. However, it is difficult to control the biochar quality, although the biochar still met the IBI Biochar Standards[23]. On the other hand, in Taiwan, most biochar was produced at simple open tanks. The quality of biochar is always more difficult to be controlled. Also the flue gas and PM 2.5 emissions were not controlled at the open tanks. Moreover, the production rate was much lower.

Therefore, designing a new commercial system with pollution prevention for mass production of biochar is an important issue to complete the loop of the agriculture and forestry circular economy in Taiwan. In 2017, supported by Taiwan Forestry Research Institute, the project "Developing the Pilot Scale Multiple Hearth Furnace with a Continuous Feeding System for Mass Production of Biochar" under the above Biochar Flagship Project was carried out to provide the information for future commercial design, and also to assist the potential manufacturers in establishing the biochar industry, and promoting the application of biochar[24]. Figure 1 shows a 100 kg/hr (feeding rate) multiple hearth furnace with a continuous feeding system for mass production of biochar installed at National Chung Hsing University, Taichung, Taiwan[25.]

The requirements of this pilot scale biochar production system focused on

1. Mass production of biochar;
2. Recovery of liquid byproducts (e.g., vinegar) for agricultural utilization;
3. Good quality of biochar based on the pore diameter by controlling the carbonization temperatures; and
4. Flue gas emissions that meet the environmental standards[26.]

The preliminary results[27] show that feeding 100 kg/hr of mixed wood pellet (from pruning street trees) into the furnace can generate about 20 kg/hr biochar under the operation temperature at 600oC. The byproduct of vinegar is about 0.06 L/L/hr, and can be diluted to 100 ppm for agricultural utilization. The property of produced biochar met the European Biochar Certificate (EBC Std.)[28]. The flue gas emissions also met the Taiwanese Stationary Pollution Source Air Pollutant Emissions Standards[29].

Nevertheless, the term "biochar" does not appear in the legislation system in Taiwan. The legislation of biochar application is an important indicator for proving a good environment for a much better utilization of biochar. However, the biochar standard can be issued first before legislation. Currently Taiwan Agricultural Chemicals and Toxic Substances Research Institute (TACTRI) has been assigned to drawing the Taiwan biochar standards based on IBI's standard under the Biochar Flagship Project before 2020[30]. According to biochar standards drawn by IBI[31], the standard for biochar

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[21] Executive Yuan, First Quarter Implementation Report on the Industry Innovation Flagship Project (2019). (*in Chinese*)
[22] Supra note 18.
[23] International Biochar Initiative, Standardized Product Definition and Product Testing Guidelines for Biochar that is Used in Soil. Ver. 2.1 (2015).
[24] Wu, K.-T., Developing the Pilot Scale Multiple Hearth Furnace with a Continuous Feeding System for Mass Production of Biochar, Final Report (No. 106AS-18.2.2-FI-G3(3)), National Chung Hsing University, Taichung, Taiwan (2017).
[25] Ibid.
[26] Ibid.
[27] Wu, K.-T., Developing the Pilot Scale Multiple Hearth Furnace with a Continuous Feeding System for Mass Production of Biochar, Final Report (No. 107AS-18.2.2-FI-G1(3)), National Chung Hsing University, Taichung, Taiwan (2018).
[28] European Biochar Foundation, Guidelines of the European Biochar Certificate - Version 8.2E (2019).
[29] Environmental Protection Administration (EPA), Stationary Pollution Source Air Pollutant Emissions Standards, Taiwan (2013).
[30] Liang, Y. J., Using Biochar as a Microbial Carrier to Form a Water Retainers and the Environmental Safety Evaluation of the Biochar Products Thereof, Final Report, Taiwan Agricultural Chemicals and Toxic Substances Research Institute (2018).

characteristics includes basic utility properties, toxicant assessment, and soil enhancement properties. For basic utility properties, it consists of moisture, organic carbon and hydrogen, total nitrogen, total ash, pH, electrical conductivity, liming, and particle size distribution. To assess toxicant, the items including polycyclic aromatic hydrocarbons (PAHs), dioxins/furans (PCDD/Fs), polychlorinated biphenyls (PCBs), cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium , zinc, boron, chlorine, and sodium. In addition, for soil enhancement properties, the measurement should contain mineral nitrogen (ammonium and nitrate), total phosphorus and potassium, available phosphorous, total calcium, magnesium and sulfur, available calcium, magnesium and sulfate-s, volatile matter, total surface area, and external surface area.

The business model is another key for successful applying biochar in constructing the agriculture and forestry circular economy. At present, the farmers cannot afford to build a large scale biochar production system. Therefore, the potential owners of the biochar production system could be farmers associations, cooperatives, communities, and agriculture production and marketing groups. These organizations can provide the biochar furnace to assist farmers in producing biochar under the long payback years. However, the assessment research should be conducted in the near future.

In conclusion, we believe that through the performance of the pilot scale biochar production system, the Taiwanese agriculture and forestry circular economy would be established promptly and successfully.

Fig. 1. 100 kg/hr (feeding rate) multiple hearth furnace with a continuous feeding system for mass production of biochar[32]

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[31] Supra note 23.
[32] Supra note 24.