Biochar

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Biochar, a carbon-rich material, is a by-product of pyrolysis (a thermo-chemical reaction in oxygen-depleted or oxygen-limited atmospheres). [1][2][3]

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1. Introduction

Questions have been raised on peat moss, the most commonly used greenhouse medium with its ideal properties for plant growth, due to environmental impacts and economic concerns [4][5][6]. Overharvesting peat moss can cause environmental issues such as rare wildlife habitat destruction, wetland ecosystem disturbance, and climate change interference [5][6]. Moreover, the price of peat moss has been rising, which causes economic concerns and could hinder growers' profits, especially when transportation costs are considered [7].

Therefore, attention has shifted to biochar (BC) as a peat moss alternative due to its numerous advantages [6][8]. Biochar can be derived from various sources, such as green waste [9], wood [10], straw [11][12][13][14][15], bark [16], rice hulls [17], and wheat straw [13][18], making it readily available. For the same reason, BC can be generated faster and is not a limited resource like peat moss, presenting great environmental potential as a peat moss alternative. Furthermore, greenhouse gas emissions could be drastically reduced when BC is prepared from agricultural wastes, which otherwise would be incinerated, resulting in greenhouse gas emissions [19]. Additionally, the BC price may be competitive if BC is available locally. The average BC price is $78.57 m^{-3}, less than half the price of peat moss ($173.93 m^{-3}), presenting a great economic advantage as a peat moss alternative [20][21]. Moreover, different waste biomass and waste heat utilized during BC production process could bring significant savings for the overall economy [22].

Biochar's potential as an alternative container substrate for peat moss has been documented in many studies. For instance, Guo et al. [23][24] observed that pinewood BC (80%, vol.) with peat moss-based substrate increased the growth of both poinsettia and Easter lily. A study by Huang et al. [25] showed that mixing 70% (vol.) mixed hardwood BC with two composts resulted in similar or better basil and tomato plant growth compared to a peat moss-based commercial substrate. Similarly, Yu et al. [26] showed that up to 70% (vol.) of mixed hardwood BC or sugarcane bagasse BC blended with peat moss can be used to grow container tomato and basil seedlings. Tian et al. [9] stated that 50% (vol.) green waste BC increased the total biomass of Calathea plants by 22% compared to those in 100% peat moss substrate. Additionally, Headlee et al. [27] demonstrated that a red oak BC feedstock mixture with vermiculite increased the total biomass and shoot biomass of hybrid poplar cuttings. Yan et al. [28] showed that 80% (vol.) mixed hardwood BC blended with 20% commercial peat moss-based substrate could be used as mixtures for different types mint plants growth without negative effects.

Incorporating compost with BC as a container substrate improves its physical and chemical properties and thus benefits plant growth [29]. Vermicompost (VC; the end product of earthworms breaking down organic waste) [30] and chicken manure compost (CM; the waste resulting from the poultry industry) [31][32] are the composts used in containers. Vermicompost and CM both have fine textures and are rich in nutrients, which could alter substrate properties and provide extra nutrients [25][33]. For instance, Huang et al. [25] demonstrated that adding 5% (vol.) VC or CM to a BC-amended substrate improved tomato and basil growth.

Adding mycorrhizae (MC) to container media, in the presence of BC, could also improve plant growth due to its symbiotic relationship with plants [34][35]. In this symbiosis, MC provide the host plant with mineral nutrients, especially phosphorus (P), and water in exchange for photosynthetic products [36]. Therefore, MC could promote plant growth and plant yield by boosting nutrient uptake [37][38][39]. Mycorrhizae are commonly known to boost plants' uptake of P, a nutrient often difficult for plants to absorb due to its insoluble forms [40][41], especially when the substrate pH is higher than 7 [4]. The ideal pH range for P in a soilless substrate is 4 to 6 [4]. However, incorporating BC in the media may limit P availability because most BCs used in greenhouse studies have pH higher than 7 [4][42]. The presence of MC enhancing P availability [41], in addition to a high P content in CM and VC, is expected to compensate for P deficiencies in BC-amended soilless substrates.

Fertilizer leaching from containers during watering raises environmental concerns, and could be reduced by adding BC to the container substrate [4]. In an open greenhouse production system, excessive fertilizer is commonly used to ensure crop growth and yield, leading to increased nutrient leaching [4]. Nutrient leaching may contaminate groundwater, cause eutrophication, and release nitrous oxide (NO_2) [43]. Incorporating BC in a container substrate could reduce nutrient leaching. Yu et al. [44] reported that mixed hardwood BC can retain nutrients due to its porous structure, which may reduce nutrient leaching. Similarly, Guo et al. [23][24] showed that the fertilizer rates could be reduced when pinewood BC was added at 60–80% (vol.) without sacrificing poinsettia's or Easter lily's growth.

Peatland has been functioning as carbon sink, playing a significant role in climate change yet its climatic potential has been underappreciated [45]. It was reported that restoring peatland for carbon sequestrate was 3.4 times less nitrite costly and less land costly compared to other ways [45]. Due to the urgency of global warming and peatland's climatic potential, some countries have already taken actions to restrict peatland extraction [6]. For instance, the United Kingdom and Europe have legislated laws to protect the peatland from being overharvested [4][46]. Therefore, peat moss substitutes are needed to reduce the total amount of peat moss used in the horticulture industry.

2. Applications of Biochar

2.1. Treatment Effects on Plant Growth

Biochar mixes, MC, and F rates and their synergistic impacts can beneficially influence plant growth. Biochar can aid plant growth both directly by supplying nutrients [47] and indirectly by influencing nutrient availability via changing substrate total porosity and pH [23][48]. For instance, for poinsettia and Easter lily, adding 20−60% (vol.) pinewood BC to peat moss-based substrate increased the total stem length and the number of leaves due to the suitable total porosity and pH, which improved nutrient uptake at given F rates [9]. Peng et al. [6] demonstrated the mix of BC (20−60%) and peat moss-based substrate (80−40%) had no negative effects on basil, tomato, or chrysanthemum because suitable physical properties helped nutrient absorption. Furthermore, pinewood BC can replace a commercial peat moss-based substrate from 5−30% (vol.) without any negative impacts on gomphrena plant growth [7], resulting from mix properties and F integrated effects. Moreover, mixed hardwood BC can replace 70% (vol.) of a commercial peat moss-based substrate without negatively impacting on tomato or basil plant growth [25] due to the enhanced nutrient uptake.

Biochar can impact substrate pH, making nutrients, especially P, less available to the plant, which could be compensated by adding MC [4][49]. For example, Conversa et al. [50] showed that 30% of BC, even with a pH at 8.6 which made P less available, increased geranium plant growth because MC compensated P uptake. However, high percentage of BC (70%; vol.) induced high pH and led to N and P deficiency, which could not be compensated by MC, reducing geranium plant growth. Part of the Conversa et al. [50] results were similar to ours: tomato and pepper plants grown in BC-amended mixes (lower than 70%) had similar growth compared to those in the commercial substrate. However, in our study, the high BC rate (70% for pepper, 80% for tomato) did not result in any negative impacts on plant growth as Conversa et al. [50] reported. The difference may be due to the presence of composts (VC or CM) in our study. Additionally, our study had similar results to the study by Huang et al. [25], which showed that 70% (vol.) of mixed hardwood BC with 5% VC or CM can be used for tomato and basil plant growth with no negative impacts on plant growth. However, in our study, the results in 90% BC−5% VC mix with MC and 300 mg L^{-1} N differed from those of Huang et al. [25]. The differences could be explained by the MC, which improved nutrient uptake.

2.2. Biochar Potential Economic Value

According to the United States Department of Agriculture (USDA) and the United States Geological Survey (USGS) [51], around 0.15 M m^3 of container substrates were used for the horticulture industry with 91% (by vol.) being peat moss-based or just peat moss [51][52]. The Sunshine Mix #1 used in this study contains 80% peat moss. The estimated prices of the 70% biochar−5% vermicompost mix and Sunshine Mix #1 are \$119.7 m^{-3} and \$176.9 m^{-3}, respectively [25]. With the results in this study, if the mix 70% biochar−5% vermicompost were chosen for container plant production, 0.1 M m^3 of peat moss with an estimated value of \$ 5.98 M could be saved annually, in addition to the reduced fertilizer costs. This study showed one aspect of the economic value of biochar by replacing peat moss-based substrate; other studies also proposed the economic value of biochar by introducing it into wastewater, farming, and municipal industries [53][54][55].

2.3. Biochar Potential Climatic Value

Using biochar as a peat moss alterative could have significant potential to slow down global warming. Peatland, accounting only for around 3% of the terrestrial surface, may store 21% of the global total soil organic carbon stock of around 3000 Gt [56][57][58] and provide natural habitats for wild animals. However, the potential climatic value of peatland has been underappreciated [45]. Using alternative substrate materials such as biochar could slow down peat moss harvest, and thus slow down depleting peat bogs, which could conserve their carbon sink capability and contribute to slower global warming. According to the literature, 20−80% of peat moss can be replaced by biochar [9][28][44]. With those numbers (assuming the commercial substrate contains 75% of peat moss), an estimated 0.02 M−0.08 M m^{-3} of peat moss can be saved annually. Furthermore, with pyrolysis for bio-oil purposes, the yield of biochar ranges from 20−47% [59]. Assuming biochar yield at 30%, to produce the same amount of biochar used sufficiently for the horticulture industry (assuming replacing 50% of peat moss), nearly 0.28 M m^{-3} of agriculture waste can be converted annually, which otherwise would be incinerated and aggravate global warming [60].

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