Effect of Wood-derived Biochar as Growth and Development Medium for Kiwifruit Seedlings

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ABSTRACT

Application of biochar as a soil amendment has gained attention as a sustainable technology for environmental remediation. However, information on its use as a growing medium amendment in Bhutanese context is presently unavailable. Hence, this study assessed biochar's physical and chemical properties as well as the response of kiwifruit seedlings to biochar-amended media. Kiwifruit seedlings were grown in different locally available organic growing media containing different quantities of wood biochar. Seven different media namely: treatment 1 (compost, 100%), treatment 2 (wood biochar + compost, 25%: 75%), treatment 3 (wood biochar + compost, 50%: 50%), treatment 4 (wood biochar + compost, 75%: 25%), treatment 5 (wood biochar, 100%), treatment 6 (wood biochar + rice husk, 50%: 50%); and treatment 7 (wood biochar + vermicompost, 50%: 50%) were used. Treatments containing biochar recorded higher pH, implying biochar addition in acidic soil reduces liming need. Kiwifruit seedlings responded significantly to the biochar-amended medium as compared with the unamended controls. This was reflected in the plant growth parameters: plant girth, plant height, taproot length and the number of lateral roots. A significant effect ($P \leq 0.05$) in seedling girth (6.60 mm), height (68.60 cm), taproot length (44.40 cm), and lateral roots (25 numbers) was observed in treatment 2 (amended with 25% wood biochar). Likewise, medium prepared with 100% wood biochar (treatment 5) resulted in a minimum effect on all parameters. Our study reveals that biochar amendment can be a method for generating carbon offsets, but at quantities exceeding 25% of the total medium, no significant effect on the overall growth of plants is achieved.

Keywords: *Kiwifruit seedling; Medium; Wood biochar; Organic; Plant parameters*

1. Introduction

Intensive agricultural practices in response to global food requirement have led to the use of various agrochemicals. In reckless pursuit of enhancing crop productivity, a tremendous amount of antecedent soil organic carbon is being lost into the atmosphere (Stavi & Lal, 2012). As a result, the negative consequences of climate change like global warming, melting of ice-caps, submerging of land under water bodies, unpredictable weather pattern, incessant outbreak of pests and diseases have been intensifying. These ill effects on the environment have forced mankind to look for

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environment-friendly organic nutrient supplement alternatives. Biochar application provides opportunity as one of the organic nutrient supplement choices in farming.

Biochar is a solid carbonaceous residue made by burning biomass under oxygen-free to oxygen-deficient conditions. Wood chips, crop residues, nut shells, seed mill screenings, algae, animal manure and sewage sludge are some of the many feedstocks used in biochar production. Many experts describe the use of biochar as an age-old solution to modern problems (Mohan et al., 2018; Schouten, 2010).

Physicochemical and biological properties of the biochar depend on the type of materials used and the temperature at which pyrolysis is undertaken. In a study by Gul et al. (2015), biochar produced from crop residues at lower temperatures (< 600 ^{o}C) had higher pH and cation exchange capacity with more microorganism content than biochar produced from wood-derived feedstock pyrolyzed at higher temperatures (> 600 ^{o}C). Biochar produced at higher temperature have a larger surface area and higher porosity as reported by Mohanty et al. (2013).

According to Mohan et al. (2018), the Amazon basin contains huge amounts of sequestered carbon. In light of climate change mitigation by sequestrating recalcitrant carbon in the soil, biochar usage in farming could be a novel technology. Biochar could be potentially low cost, easily available, and environment-friendly constituent of growing media although it may not contain as many nutrients (Nemati, Simard, Fortin, & Beaudoin, 2015). Biochar helps retain nutrient and moisture of the growing medium. They observed only 11% nutrient leaching in growing media treated with biochar.

In Bhutan, the use of biochar as a soil amendment and growing media is gaining popularity. Likewise, organic agriculture has been given high priority by the Royal Government of Bhutan in the 12th Five Year Plan. Biochar has been released as a technology at the 2nd sitting of the Technology Release Committee (TRC) of the Department of Agriculture, Ministry of Agriculture and Forests convened on 29 May 2020 (DoA, 2020). Although charcoal and ash from our household hearths have been applied into the soil for ages in the country, proper assessment of their effects on soil and crop yield has not yet been studied.

Therefore, this study was conducted to assess the physico-chemical properties of media amended with different levels of biochar and their effect on the growth of kiwifruit seedling.

2. Materials and Method

2.1. Study area

This study was carried out on the research farm of the Agriculture Research and Development Center (ARDC-Wengkhar), Mongar, from June 2019 to May 2020. The site is located at 1732 m above sea level between 27^{o} 16’ 09.6’’ N and 91^{o} 16’ 19.9’’E. It falls under dry sub-tropical zone and faces north-west. The area receives close to 1000 millimetres of annual rainfall.

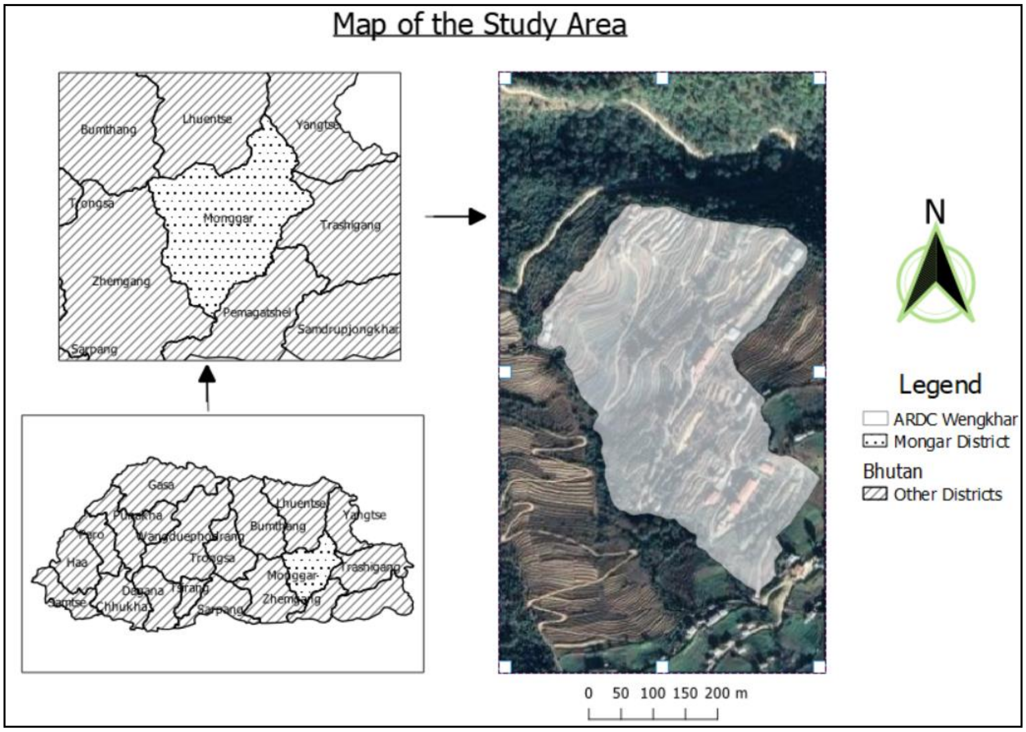

Figure 1. Map of the study site.

2.2. Experiment Setup

The experiment was laid out in random complete block design (RCBD) with seven treatments replicated three times each. About two months old or 3-leaf stage kiwifruit seedlings were transplanted in 40 * 40 * 80 mm poly tubes. Each treatment had 15 plants of which five seedlings were tagged for routine data collection.

Wood biochar was produced from pruned branches and twigs of assorted fruit plants like citrus, pear, peach, plum, chestnut and kiwifruit through the pyrolysis process. The feedstock was made into small pieces. The method adopted was a traditional which involved letting wood chips to burn underground overlayered with a cover of a thick layer of green leaves and soil. It was then ground into fine powder manually using a piece of wood or stone, followed by sieving using a wire mesh with an eye size of 0.1 * 0.1 mm. The growing media mix preparation was done adding wood biochar to different proportions in separate locally available organic substrates as follows:

i) Compost (100%)

ii) Biochar + compost (25%: 75%)

iii) Biochar + compost (50%: 50%)

iv) Biochar + compost (75%: 25%)

v) Biochar (100%)

vi) Biochar + rice husk (50%: 50%)

vii) Biochar + vermicompost (50%: 50%)

The polytubes were filled with media mixtures, and 2 to 3-leaf stage seedlings were transplanted after dipping their roots in copper oxychloride solution for an hour. Before planting the seedlings, records on plant height, stem girth, taproot length and the number of lateral roots was maintained.

Seedlings which could not survive were replaced every forth-nightly for three months and data recorded. The temperature of the media mixes was recorded with a soil thermometer. Manual irrigation was provided using watering can every two days up to three months, followed then by application of water depending on seedling and weather condition.

Plant height and stem girth data were collected after every three months. At the end of one year, data on taproot length and number of laterals were recorded by destructive sampling method.

2.3. Data collection and analysis

During the study period of one year, data on seedling height and girth were recorded quarterly. Physiochemical properties of the different potting mixes were assessed at the Soil and Plant Analytical Laboratory of the National Soil Services Center (NSSC), Department of Agriculture, Simtokha, Thimphu. Data analyses were conducted using MS Excel spreadsheet and Statistical Tool for Agricultural Research (STAR) software. After checking for normal distribution of the data, one-way analysis of variance (ANOVA) was conducted. The significance level of the treatments was tested at P level 0.05.

3. Results and Discussion

3.1. Laboratory analysis

Media mixes of different proportion had different chemical properties affecting plant nutrient availability ultimately. Treatments amended with biochar resulted in higher pH. The higher pH in media mix treated with biochar was due to increased temperature during pyrolysis that resulted in the removal of the carboxyl and hydroxyl groups of compounds from the charcoal. The media prepared with biochar alone had the highest of pH (10.17) while compost had neutral pH. Likewise, available potassium was the maximum in the treatment prepared with 50% each of biochar and vermicompost followed by the treatment composed of biochar and rice husk (50%: 50%). The compost media had the highest nitrogen content while treatment with 100% biochar showed the lowest N. Table 1. below presents the chemical properties of the different media mixes.

Table 1. Chemical characteristics of the treatments.

Treatments	Composition	pH		Available K	N
		H2O	KCL	*mg/kg* (Bray)	Percentage (%)
1	Compost (100%)	7.01 M	6.95 M	331.36 vH	0.48 M
2	Biochar + compost (25%: 75%)	7.43 vH	7.35 vH	309.47 vH	0.25 M

3	Biochar + compost (50%: 50%)	8.45 vH	8.25 vH	242.99 vH	0.19 L
4	Biochar + compost (75%: 25%)	9.58 vH	9.02 vH	171.58 vH	0.18 L
5	Biochar (100%)	10.17 vH	9.58 vH	284.11 vH	0.17 L
6	Biochar + rice husk (50%: 50%)	9.35 vH	8.47 vH	333.03 vH	0.18 L
7	Biochar + vermicompost (50%: 50%)	7.44 vH	7.00 M	338.40 vH	0.32 M

Ratings: vL-Very low, L - Low, M-Medium, H-High, vH-Very high

3.2. Seedling mortality and re-transplantation

Seedling mortality was recorded weekly and replanted until one month of the trial establishment. In the 1st week, seedling survival for all the treatments was almost the same. However, in the 2nd week, we re-planted 32 and 34 numbers of seedlings in treatment 2 and 3, respectively. The percentage of seedlings required to re-transplant gradually dropped from 75.16% in the 3rd week to 55.07 % in the fourth week where a minimum of 2 numbers of seedlings was replanted in treatments 4, 6 and 7. Maximum of 9 numbers of seedlings were planted in treatment 5. It was observed that the seedling mortality trend was the maximum in the media mixes treated with biochar. This could be attributed to higher pH values which the addition of biochar to the mixes resulted in, which subsequently led to poor nutrient availability. Also, high seedling mortality was due to excessive amount of water retained by biochar causing root suffocation and decay.

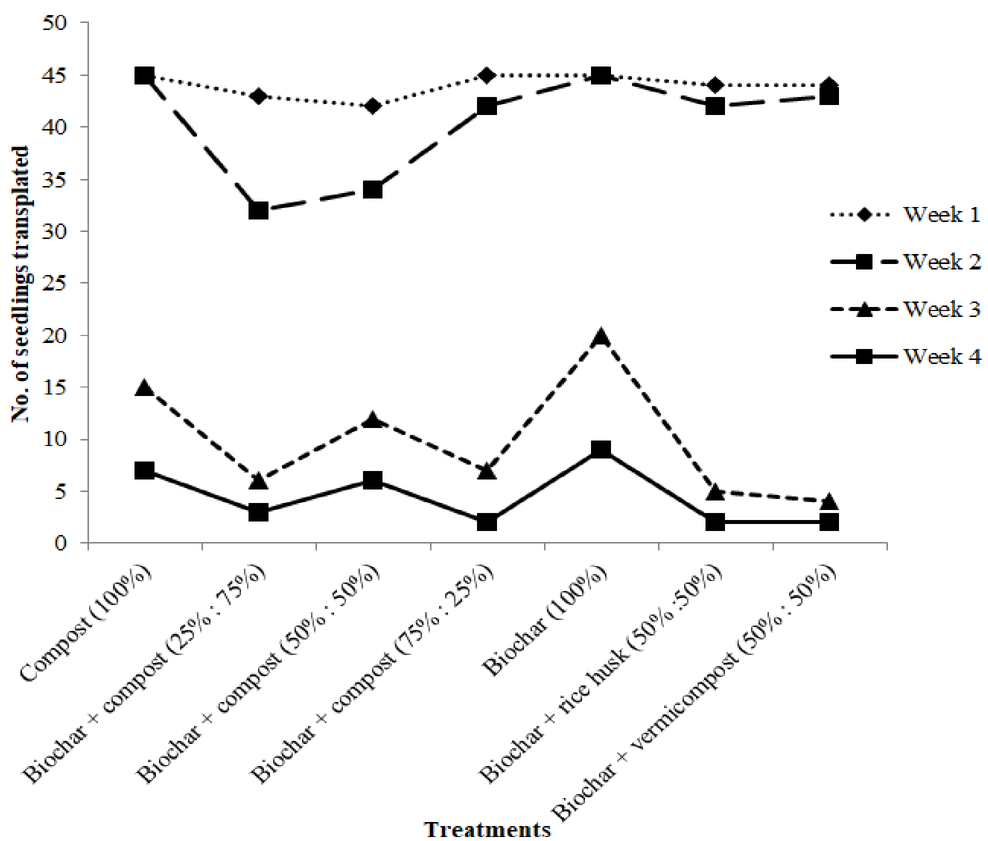

Figure 2. Number of seedlings replanted in different treatments in one month.

3.3. Above-ground seedling growth

Plant girth at 10 to 15cm from the root collar is the determining factor for a rootstock to be considered as having reached the optimum grafting stage. The rootstock is considered to have attained graftable size when its girth attains pencil size (more than 6.5 mm in diameter). It was measured using a digital vernier calliper (model: CD-S20CT) every after three months. The effect of biochar amendment on both girth and height of the seedlings was similar. Media mixes with biochar had a significant effect ($P \leq 0.5$) on the seedling girth. The maximum girth of 6.69 mm followed by 6.40mm was recorded in biochar and biochar 50% + vermicompost 50%, respectively. Likewise, the minimum effect was seen in treatment 5 (2.06 mm) where the medium was 100% wood biochar.

In a study by Ismail and Iberahim (2003), the addition of 5% biochar by weight in potted tomato had a significant effect on plant physiology and yield due to improved moisture content. Similarly, Khan et al. (2015) had observed increased production of turnip with the addition of 2% biochar than 5% when added into soil. Likewise, Graber et al. (2010) also found a significant effect on the yield of tomato and pepper with an addition of 1 to 5% by weight of wood-derived biochar into coconut fibre. Aller et al. (2018) also noted that the lower rate of biochar application yielded better corn yield than higher rates. Other factors responsible for poor growth in seedlings with the increase in biochar proportion could be due to a decrease in nitrogen uptake by the seedlings as reported by Rondon, Lehmann, Ramírez, and Hurtado (2007). Their study reported that nitrogen uptake by bean reduced from 14% to 50% when biochar application was increased from 30 g to 90 g per kilogram of soil.

The seedling height was measured from root collar till the tip of the vine using a plastic ruler at every three months interval. At the end of the year, maximum height (68.60 cm) was observed in 25% + compost 75% and a minimum of 7.56 cm was recorded in 100% wood biochar. It was also observed that with the increase in the quantity of biochar powder, the effect was negative. This could be due to the creation of an optimum environment like air-filled porosity, water-holding capacity and nutrient supplement ability of the medium for growth and development of the seedlings. However, when the proportion of biochar was increased, the ability of the medium to hold water increases but lacked the nutrients for the seedlings. Table 2. below shows the effect of different media mixes on seedlings girth and length.

Table 2. Effect of treatments on above-ground growth parameters of the seedlings.

Treatment	Composition	Seedling girth (mm)	Seedling height (cm)
1	Compost (100%)	5.68^{b}	41.80^{c}
2	Biochar + compost (25% : 75%)	6.69^{a}	68.60^{a}
3	Biochar + compost (50% : 50%)	5.72^{b}	41.20^{c}
4	Biochar + compost (75% : 25%)	3.53^{c}	12.23^{e}

5	Biochar (100%)	2.06^{d}	7.56^{f}
6	Biochar + rice husk (50% : 50%)	3.51^{c}	18.50^{d}
7	Biochar + vermicompost (50% : 50%)	6.40^{a}	49.17^{b}
	CV (%)	9.08	11.34
	P-value	0.00	0.00

Means with the same alphabets within the column are not significantly different.

3.4. Underground seedling growth

The underground parameters assessed were taproot length and number of lateral roots that had originated from the taproot. Significant effect on tap root length was observed in biochar 25% and compost 75% (44.40 cm) followed by biochar 50% and vermicompost 50% (43.20 cm). On the other hand, the least effect was recorded in 100% biochar 5 (22.13 cm).

Similarly, the taproot length significantly correlated to the number of lateral roots. This means that longer the length of the taproot higher the number of lateral roots. The highest number of laterals was seen in biochar 25% and compost 75% (25 numbers) followed by biochar 50% and vermicompost 50% (24 numbers). 100% biochar had the lowest (12 numbers). There was a significant difference in the effect on lateral roots between biochar 25% and compost 75% and treatment 7 (biochar 50% and vermicompost 50%) with that of 100% compost. However, there was no large difference in the means among the roots and shoots parameters. This may be because biochar held maximum water during irrigation which affected the root growth. The is partly substantiated by Major (2010) who explained that biochar holds a significant amount of water. Manickam et al. (2015) also reported that the addition of 4% to 5% of biochar in sandy soil resulted in a significant increase in plant-available water content from 5% to 8%.

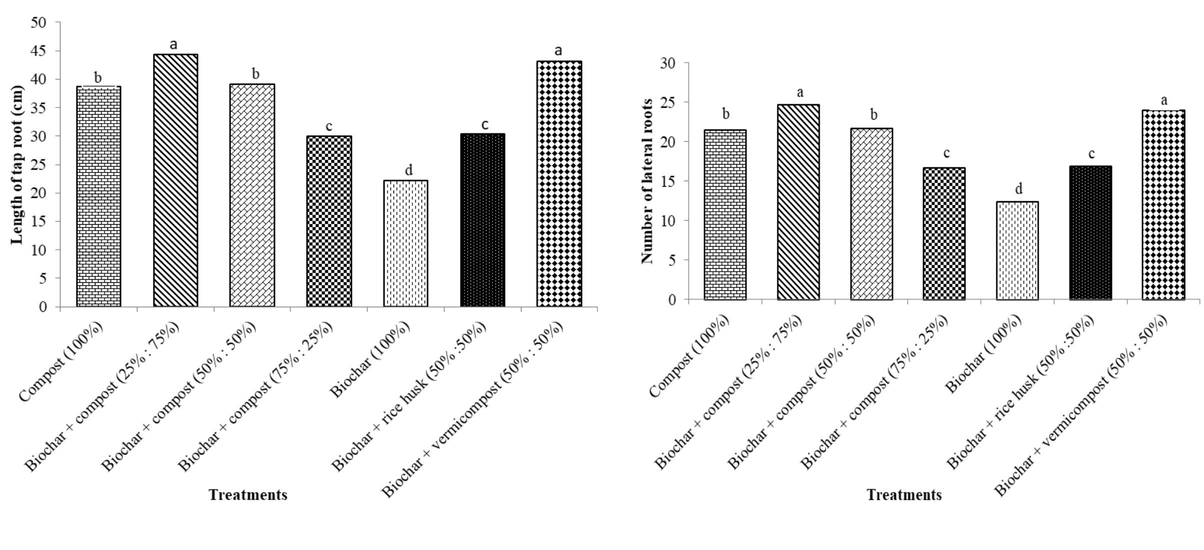

Figure 3. Effect of treatment on underground growth parameter.

On the other hand, unlike other organic soil amendments, wood biochar contained minimal plant nutrients which affected the seedling development. Also, bigger particle size-biochar derived from wood have larger pores retaining excessive water. A study by Sorrenti, Muzzi, and Toselli (2019) reported that biochar amendment influenced peach root physiology rather than its biomass. Likewise, in another report by Bruun et al. (2014), barley root density was found to have been significantly influenced with 2% straw biochar addition than by 4%.

4. Conclusion

Although biochar application has been considered to improve soil physico-chemical properties and enhance soil fertility, increase in the percentage of biochar in the growing medium did not show a positive effect in this study. Additionally, biochar proportionately increases the pH of the medium affecting the availability of nutrients to the seedlings. Wood biochar production and use can be a renewed organic soil management practice for poor quality and low pH soils. Pyrolysis without proper control of temperature yields poor quality biochar. To improve the quality of biochar, we need to have better equipment and enhanced skills. To help better control pyrolysis temperature, we need to develop or introduce kiln or huge chamber for mass production with temperature control functions. Further, we also recommend an in-depth study to assess the quality of biochar from different feedstocks and their application effects on different soil types. There is also the requirement of numerous long-term studies to draw clear conclusion regarding the effect of biochar usage on carbon sequestration potential in our context.

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