Biochar effects on the seedling quality of *Quercus serrata* and *Prunus sargentii* in a containerized production system

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**ABSTRACT**

Biochars are used to improve soil quality and crop productivity as well as to increase carbon sequestration in soil. However, it is important to identify the characteristics of biochar prior to its application because of the positive and negative effects on soil and crop productivity. The purpose of this study was to investigate the effects of charcoals on the growth and seedling quality of *Quercus serrata* and *Prunus sargentii* in a containerized seedling production system. Two of the charcoals used in our research were from oak tree; one produced at 1200°C and the other at 700-800°C, and a bamboo charcoal produced at about 800°C. Three charcoals were mixed with artificial soil (peat moss, perlite, and vermicultile with a ratio of 1:1:1 (v/v/v)), and applied commercial fertilizer at two concentrations; 0.5 and 1.0 g L⁻¹. Growth parameters, such as height, root collar diameter, and dry weight, were decreased in charcoal treatments compared to control. However, charcoal treatments significantly increased the quality index of seedlings by 8.3% in *Q. serrata* and by 19.9% in *P. sargentii*. Our results suggested that charcoal can be applied to improve seedling quality in the containerized *Q. serrata* and *P. sargentii* seedling production system.

**Introduction**

Biochar is a kind of charcoal manufactured under high temperatures by using crop remains, animal manure, or any type of organic waste materials (Kelsi 2010). Most of its usage as a soil amendment was in agriculture field in order to increase crop productivity, enhance soil physical and chemical quality, increase carbon sequestration in the soil, and filtrate percolating soil water (Lehmann and Joseph 2009; Zhang et al. 2012; Oh et al. 2017). Biochar application to forestry sectors has been suggested to reduce the possible negative impacts of forest biomass removal by whole tree harvesting, pre commercial thinning, and hazardous fuel reductions because of its carbon sequestration, nutrient supply, and liming capacity (McElligott et al. 2011). However, little is known about the consequences of biochar application to forests as most research on biochar additions has involved in agricultural systems (Wardle et al. 1998; Spokas et al. 2012). Biochar properties could be different based on the original feedstock from which they are produced (Lehmann 2007; Downie et al. 2009; Cho et al. 2017), and the levels of temperature and heating rate during pyrolysis (Liang et al. 2006; Cheng et al. 2008; Watanabe et al. 2014). Understanding the positive or negative effects of different biochar additions on soil and crop tree growth is crucial, as biochar properties can vary by different feedstock type and conditions of pyrolysis (Robertson et al. 2012; Mukherjee and Zimmerman 2013; Jindo et al. 2014). Therefore, it should be well noticed that different effects to soil and plant growth can be resulted from application of biochar with different feedstock (Amontette et al. 2009). Even biochar resulted from same material with different temperatures can have different effects to soil on which they are applied. For example, biochars produced from crop straws at 500°C have greater amelioration effects on soil acidity compared with that produced at 300°C from the same material (Yuan et al. 2011). Biochar has a potential negative impact on soil quality because of N immobilization and increasing soil pH in alkaline soils (Lehmann et al. 2003; Novak et al. 2009). Zheng et al. (2010) observed that biochars together with nitrogen fertilizer addition has a synergetic effect on corn yield, as it was increased by 20%, 25%, and 47% after application of biochars only, nitrogen fertilizer only, and biochars plus nitrogen fertilizer, respectively. These effects depend on biochar’s unique physical, chemical, and biological properties and its interactions with soil and plant communities.

The purpose of this study was to investigate the effects of biochars prepared from different biomaterials (two charcoals from oak tree and one from bamboo) on the growth and quality of *Quercus serrata* and *Prunus sargentii* seedlings, which has been used in...
wood industry (Park et al. 2016), in a containerized seedling production system. This study can expand our knowledge about the characteristics of biomaterials that will provide the most effective results in seedling production in a containerized system.

Materials and methods

Study sites and species

This research was conducted in the greenhouse located in Chungnam National University, Daejeon, South Korea (36°22′N, 127°21′E) from April 21 to October 4, 2016. The mean annual temperature in the area was 22.5 °C and the mean humidity was 78.6% in 2016.

Two tree species, Quercus serrata and Prunus sargentii, were used in this study. Q. serrata acorns and P. sargentii seeds were germinated in March 2016 at the Forest Technology and Management Research Center, National Institute of Forest Science, South Korea, and delivered to the greenhouse in Chungnam National University in the middle of April 2016.

Experimental design

Each tray (32 cm × 40 cm) used for planting contained 20 cells that were 6.8 cm in diameter, 15 cm deep, and had a volume of 400 mL. The cells were filled with a mixture of peat moss, perlite, and vermiculite in a ratio of 1:1:1 (v/v/v) (Table 1), following the recommendation for growth of tree seedlings in a containerized seedling production system (Landis et al. 1990).

Three types of biochar were purchased: oak charcoal produced at high temperature (about 1200 °C, hereafter “OakH” ) and low temperature (about 700–800 °C, hereafter “OakL”), and bamboo charcoal (hereafter “Bamboo”) produced at about 800 °C. The 4 × 2 experimental design was applied to test the effects of charcoal type and fertilization on Q. serrata and P. sargentii growth and quality of seedlings. This experiment included treatments with three types of biochar and a ‘control’ and two levels of fertilization. The control consisted of 400 mL soil mixture with no biochar added, and in the other three treatments, 40 mL of charcoal was mixed with 360 mL of soil mixture creating a soil mixture with 10% biochar. Each treatment was replicated five times in a completely randomized design.

The seedlings were planted in every second cell, with a blank cell in between; 10 seedlings were planted in each tray. The planted seedlings were of similar height and root collar diameter. The trays were then placed in the greenhouse on a platform that was elevated 60 cm above the floor. Fertilizer (110 mL) was applied to each tray at two concentrations, 0.5 g L⁻¹ for 1 × and 1 g L⁻¹ for 2 × of MultiFeed20 fertilizer (20N:20P₂O₅:20K₂O; Haifa Chemical, Israel), once a week for 10 consecutive weeks. Each tray was treated with both concentrations with 5 seedlings for 1 × and the other 5 for 2 × fertilization. Irrigation was applied daily for 20 min, approximately 110 mL per cell, and the trays’ positions were changed every 2 weeks to reduce the bias associated with variations in environmental conditions such as unequal water spraying.

Growth measurements

During the experiment, the seedlings’ height and root collar diameter were measured every month from June to September. Seedling height was measured from the ground to the apical meristem, while the root collar diameter was measured 1 cm above the ground. All seedlings were harvested in October 2016 and divided into stem, leaf, and root. The roots were washed with tap water to remove all soil particles from the roots. All components were oven-dried to constant weight at 65 °C for 72 h.

Dickson’s quality index

To quantify the quality of seedlings, Dickson’s quality index was calculated as follows: Quality index = SD/ (HD + SR), where SD is seedling’s total dry weight (g), HD is the ratio of seedlings height (cm) to root collar diameter (mm), and SR is the ratio of shoot weight (g) to root dry weight (g) (Deans et al. 1989; Bayala et al. 2009; Cho et al. 2017).

Statistical analysis

Analysis of variance (ANOVA) with Duncan’s multiple comparison tests was applied to test the effects of the three treatments with charcoal type and the two levels of fertilization on seedling height, root collar diameter, dry weight, and quality index measured in September 2016. The change in height and root collar diameter across the months was analyzed using one-way ANOVA for each treatment. All probabilities were tested at a significance level of 0.05.

Results

There was no significant interaction effect of charcoal type and fertilization on all measured values (Table 2). The seedling height of both species was significantly influenced by charcoal type, but not by the level of fertilizer (Table 2, Figure 1). Seedling growth and quality of seedlings.

| Bulk density (g m⁻³) | pH | Electric conductivity (ds m⁻¹) | Organic matter (%) | Total N (%) | P₂O₅ (mg kg⁻¹) | K⁺ | Ca²⁺ | Mg²⁺ | CEC (cmol, kg⁻¹) |
|---------------------|----|-------------------------------|-------------------|-------------|----------------|----|------|------|-----------------|
| 0.37                | 6.1| 0.06                          | 4.0               | 0.08        | 3.0            | 0.3 | 3.3  | 2.5  | 24.3            |
|                     |    |                               |                   |             |                |     |      |      |                 |

Table 1. The physical and chemical properties of growing media (artificial soil) before mixing with biochars (revised from Cho 2015).
height growth in the control and OakL treatment was significantly higher than that in OakH and Bamboo treatments.

The growth of the root collar diameter was significantly reduced in OakH treatment compared to that in other treatments in *Q. serrata* (Table 2, Figure 2). Similar to seedling height, the growth of the root collar diameter was not statistically different between the two fertilization treatments. The change in leaf, stem, and root biomass followed a similar pattern to that of the root collar diameter growth among the treatments with different charcoal types and fertilizer amounts (Table 2, Figure 3). However, the difference in dry weight was very small; the total biomass ranged from 12.7 to 13.8 g tree\(^{-1}\) for *Q. serrata* and from 14.4 to 15.3 g tree\(^{-1}\) for *P. sargentii*.

**Figure 1.** Height growth of (a) *Quercus serrata* and (b) *Prunus sargentii* at 1× fertilization (left) and 2× fertilization (right) across 3 biochars. Different letters represent significant differences between biochar treatments in both fertilization treatments. Vertical bars represent one standard error of the mean (\(n = 5\)).

**Table 2.** ANOVA table for growth parameters of *Quercus serrata* and *Prunus sargentii* on biochar type and fertilization treatments.

| Species      | Source of variable | Degree of freedom | Height | Root collar diameter | Leaf | Stem | Root | Total | Quality index |
|--------------|--------------------|-------------------|--------|----------------------|------|------|------|-------|---------------|
| *Quercus serrata* | Biochar type       | 3                 | <0.01  | <0.01                | <0.01| <0.01| <0.01| <0.01| 0.07          |
|              | Fertilization      | 1                 | 0.56   | 0.71                 | 0.31 | 0.86 | 0.58 | 0.49 | 0.34          |
| *Prunus sargentii* | Biochar type × Fertilization | 3     | 0.98   | 0.57                 | 0.74 | 0.77 | 0.86 | 0.87 | 0.57          |
|              | Fertilization      | 1                 | 0.21   | 0.37                 | 0.84 | 0.14 | 0.97 | 0.72 | 0.63          |
|              | Biochar type × Fertilization | 3     | 0.77   | 0.73                 | 0.82 | 0.99 | 0.76 | 0.84 | 0.83          |

Quality index, which is one of the most comprehensive indexes that evaluate seedling quality, was
significantly higher (by 8.3% for *Q. serrata* and 19.9% for *P. sargentii*) in all charcoal treatments as compared with that in the control (Table 2, Figure 4). The quality index was not statistically different between the two fertilization treatments.

**Discussion**

Charcoal treatments generally decreased the height, root collar diameter, and dry weight of seedlings compared to that in the control, but these parameters remained above the minimum growth required by the national guidelines of the Korea Forest Service (Lee et al. 2009). The growing medium used as a control of the experiment in this study has developed and used for producing container seedlings (Landis et al. 1990): because it has good cultural and operational characteristics, for example slightly acid pH, high CEC, large or small pores for aeration and water holding capacity, low bulk density, and plug formation. However, charcoals used in this study are strong in basicity and may alter the pH of the growing medium to decrease the availability of nutrients.

This study did not examine the effect of other biochar properties, such as pH, carbon content, or pore size across temperatures during the pyrolysis, but these properties should be examined to verify the mechanism of charcoal effects on seedling responses. Shaaban et al. (2014) reported that the final structural and physico-chemical properties of biochar was significantly influenced by pyrolysis temperature, because of the release of volatiles as well as the formation and volatilization of intermediate melts. Sun et al. (2014) identified the contribution of porosity by pyrolysis temperature on surface area, surface functional groups, cation exchange capacity, and the H/C and O/C ratios of charcoals. Gai et al. (2014) conducted a study on 12 types of biochar and reported that biochar yield and contents of N, hydrogen, and oxygen were decreased as pyrolysis temperature increased, while ash and carbon contents, and pH, were increased with increasing temperature of pyrolysis from 400°C to 700°C. In terms of carbon sequestration, Brassard et al. (2016) observed that

![Figure 2. Root collar diameter growth of (a) *Quercus serrata* and (b) *Prunus sargentii* at 1× fertilization (left) and 2× fertilization (right) across 3 biochars. Different letters represent significant differences between biochar treatments in both fertilization treatments. Vertical bars represent one standard error of the mean (*n = 5*).](image-url)
biochars with an H/C ratio <0.4 and O/C ratio <0.2, that were produced at a higher pyrolysis temperature, might have high sequestration potential. High pyrolysis temperature produced biochars with low N content, and consequently high C/N ratio (>30), leading to improve N using efficiency by reducing N\textsubscript{2}O emissions (Brassard et al. 2016) and NH\textsubscript{4}\textsuperscript{+} drainage from containers (Gai et al. 2014).

Even though aboveground morphology, such as height and root collar diameter, was the most useful...
characteristic in assessing quality of seedlings, it is not always an accurate predictor of seedlings’ performance after outplanting (Chavasse 1977; Thompson and Schultz 1995; Jacobs et al. 2005). All biochar treatments increased seedling quality index which is one of the comprehensive indices to evaluate seedling quality (Figure 4). Achieving better seedling quality might be due to the improved water retention in nursery substrates amended with biochar in a containerized production system (Steiner et al. 2007; Graber et al. 2010; Altland and Krause 2012; Rezende et al. 2016). Although outplanting performance of the seedlings was not tested in this study, we expected that under field conditions, soil amended with charcoal will likely to improve the performance of seedlings, as suggested by the overall increase of 14.1% in quality index of the seedlings of both species when grown in soil amended with 10% charcoal.

There were no significant differences in growth or seedling quality index between fertilization treatments. Application of fertilization with biochar to soil may also have negative effects on soil properties and plant growth (Chan and Xu 2009), but Landis et al. (1990) stated that some characteristics of biochars such as increased water-holding capacity, reduced bulk density, and supplementation with additional cation exchange sites may improve seedling production conditions in small-volume containers. Although nutrients may be lacking in all treatments, these responses might suggest 50% of customary fertilization to achieve the minimum growth required by the national guidelines of the Korea Forest Service (Lee et al. 2009). Park et al. (2012) have reported that the standard dose can contaminate the soil and water quality surrounding the nursery because seedlings could not consume all of the nutrients.

The main reason for the quality index of P. sargentii was higher than that of Q. serrata might be due to the root responses to biochar treatments because the former tree species was more sensitive than the latter (Burns and Honkala 1990). Root biomass, which is belowground parts, and its physiological status might be a more accurate indicator of seedling potentials (Davis and Jacobs 2005), as seedlings with improved morphological and physiological root systems are more likely to be well adapted during field planting (Duryea 1985; Mattsson 1997).

In conclusion, on the basis of the data presented herein, we recommend using growing medium with 10% charcoal to increase the quality index of the seedlings. This will in turn promote field performance of nursery seedlings, which is essential for successful plantations in the forestry sector. Our study did not assess the growth of nursery seedlings after outplanting and therefore further studies should focus on the performance of field-grown Q. serrata and P. sargentii planted in soil with 10% charcoal amendment.

Acknowledgements

This study was carried out with the support of "R&D Program for Forest Science Technology (Project No. 2014109C10-1820-AA01)” provided by Korea Forest Service(Korea Forestry Promotion Institute). Moreover, we would like to give our appreciation to Asian Forest Cooperation Organization (AfCoO) for supporting Aung Aung to study in Republic of Korea. The authors would like to thank Afroja Rahman and Youngtak Ko for their great help with the greenhouse work.

Disclosure statement

The authors declare no potential conflict of interest.

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