Vol. 12(2): 480-493, May 2024

DOI: https://doi.org/10.23960/jsl.v12i2.902

Jurnal Sylva Lestari

P-ISSN: 2339-0913
E-ISSN: 2549-5747

Journal homepage: https://sylvalestari.fp.unila.ac.id

Full Length Research Article

Interactive Effect of Fertilization and Biochar on the Growth of *Juniperus scopulorum* under Various Shading and Irrigation Conditions

Sk Abidur Rahman[1,†], Hyun Ju Lee[1,†], Mark Bryan Carayugan[1], Bangun Adi Wijaya[1], Woo Bin Youn[1], Jong Chan Yeo[1], Sang Hyun Park[1], Ye Jin Kong[1], Hyung Won Kim[1], Julia Inacio Carvalho[1], Myo Min Latt[1], Wencelito Palis Hintural[1], Ji Young An[2], Byung Bae Park[1,*]

[1] Department of Environment and Forest Resources, College of Agriculture and Life Sciences, Chungnam National University, Daejeon, Republic of Korea
[2] Division of Environmental and Forest Science, College of Agriculture and Life Sciences, Gyeongsang National University, Jinju, Republic of Korea
[†] These two authors contributed equally to this work as the first authors
[*] Corresponding Author. E-mail address: bbpark@cnu.ac.kr

ARTICLE HISTORY:

Received: 13 February 2024
Peer review completed: 23 April 2024
Received in revised form: 3 May 2024
Accepted: 28 May 2024

KEYWORDS:

Biochar
Fertilizer
Irrigation
Juniperus scopulorum
Shading

ABSTRACT

The global demand for landscape trees has been amplified with the increasing anthropogenic activity. South Korea has also witnessed a surge in demand for landscape plants, among others, *Juniperus scopulorum* gaining popularity for its ecological, economic, adaptability, and management attributes. However, the optimum management practice for high-quality Juniperus seedling production in South Korea remains unknown. This research was conducted on the one-to-two-years-old two cultivars of *J. scopulorum,* namely Blue Angel and Blue Heaven seedlings, to investigate the combined impacts of varying fertilizer concentrations (0 ppm, 150 ppm, 300 ppm) and biochar content (0% and 20%) under contrasting shading intensities (0%, 35%, 55%) and irrigation levels (200 ml, 400 ml, 800 ml). The study revealed that biochar and fertilizer amendment significantly ($p < 0.01$ and $p < 0.05$) enhanced the height and root collar diameter growth in Blue Angel and Blue Heaven in light shade intensity (0–35%) and higher irrigation (400–800 ml) conditions. Similarly, seedlings planted in 20% biochar and 300 ppm fertilizer yielded higher foliar, stem, and root biomass in low shade and higher irrigation conditions. The amount of shade and irrigation and their interactions significantly affected the morphological growth of seedlings for both cultivars, causing positive interaction with soil amendment (biochar and fertilizer application). These findings suggest that efficient seedling production of *J. scopulorum* management should focus primarily on light shading and moderate irrigation under biochar and higher fertilizer application. The research contributes valuable insights toward optimizing management practices and reducing costs associated with *J. scopulorum* seedling production in the region.

1. Introduction

With worldwide anthropogenic activity, the demand for urban greening grows. Trees are significant assets to livable cities, offering vital environmental services to battle issues such as pollution (Nowak et al. 2018), urban heat (Lee et al. 2021), and flooding (Viezzer et al. 2022), as well as improving social cohesion, human health, and well-being (Wolf et al. 2020). Expansion of urban forestation is critical for Korea, as 91% of the Korean population lives in cities with insufficient green. In Korea, there are 8.32 square meters (m^2) of green area for every person in Seoul, falling short of the World Health Organization's requirement of 9 m^2/person (WHO 2012). Moreover, green cities are one of the main objectives in Korea's green growth strategy for raising the quality of life by 2030. The significant surge in domestic landscape plant production in South Korea, soaring by over 66.5% from 47.13 million trees in 2005 to 78.46 million trees in 2015 (KFS 2016), highlights the need.

Various factors must be considered when selecting plant species for landscaping to ensure the plant's success and suitability for the intended environment. Schutzki (2005) proposed a comprehensive set of criteria for choosing urban landscape species, encompassing function, aesthetics, adaptability, management, and performance. Aligned with these criteria, *Juniperus scopulorum* makes it a suitable choice due to its versatility, economic potential, and adaptability to various environmental conditions. These conifers offer a valuable option for landscaping due to their diversity, rich colors, long ornamental seasons, and robust characteristics. Besides its ecological value, it has remarkable stress resistance and withstands adverse climatic circumstances such as winter, rocky slopes, shallow soils, frost, and water stress (Mathaux et al. 2016; Evren and Kaya 2020; Rawat and Everson 2013). As an evergreen species with persistent foliage year-round, it contributes to its long-term survival and makes it a resilient and adaptable landscape plant. Therefore, *J. scopulorum* has become recognized and famous for its tolerance of numerous stresses, its long-lived history in urban landscapes, and the issues associated with climate change.

As mentioned above, *J. scopulorum* can grow in several planting conditions; the early stage of this species needs favorable conditions for growing. Seedlings are the most sensitive and vulnerable stage of the plant lifecycle. Understanding seedling optimal conditions may aid in producing robust plants under urban stress (Hernandez et al. 2024). Seedling growth is heavily influenced by naturally occurring resources (such as light, water, and nutrients), and disturbances (such as pollutants, high temperature, extreme drought as inundation, and limited space above- and below-ground inhibit proper root and crown formation and increase susceptibility to insects and disease) (Bhadouria et al. 2016). *J. scopulorum* thrives well in full sunlight. Studies have historically supported the idea that junipers are shade tolerant in the seedlings and saplings stage, which become shade intolerant as they grow old (Scianna 2000). For rocky mountain junipers, achieving the right balance of growth in nursery shade depends on irrigation conditions, as both simultaneously ameliorate microclimate and enhance growth and development. While they require optimal watering during the seedling stage, they are not tolerant of waterlogged conditions (Huxman et al. 2005). Despite their drought tolerance as mature conifers, junipers still benefit from adequate irrigation during their sapling stage (Farsi et al. 2017). Therefore, intricate shading and irrigation interacting dynamics are needed to understand the underlying juniper seedling production.

Subsequently, biochar addition to the seedling shading and irrigation conditions will help reduce abiotic stress. Biochar, a carbon-rich product derived from the pyrolysis of organic materials, has garnered significant attention due to its potential to enhance soil fertility, augment water retention, carbon sequester, and boost nutrient accessibility in nursery seedling production (Basso et al. 2013; Liu et al. 2017; Masiello et al. 2015; Yu et al. 2013). Biochar is low in nutrients, which is why the use of biochar in conjunction with fertilizer is gaining popularity (Syuhada et al. 2016). Nutrient attribution with biochar at the early growth stage could contribute to vigorous and robust seedling growth compared to biochar with no fertilizer. A meta-analysis on combined biochar and fertilizer application by Bai et al. (2022) showed that, individually, biochar and inorganic fertilizer increased crop yield by 25.3%. Therefore, adhering to the recommended amendment of fertilizer doses with biochar is crucial, as excessive application can have adverse effects. In these contexts, a pressing need is a preference for optimum growth conditions for good quality seedlings of *J. scopolurum* cultivars using shading, irrigation, biochar, and fertilizers (Di Lonardo et al. 2017).

Knowing the interaction of biochar and fertilizer, as well as a combination of shading and irrigation effects on the seedling preparation of *J scopulorum* is imperative. This research aims to identify the effect of biochar addition mixed with fertilizer at different levels of shade and irrigation. We pursued the following objectives: (1) to determine irrigation and shading application levels suitable for the growth of *J. scopulorum* at different fertilization and biochar conditions, and (2) to identify the influence of fertilizer and biochar interaction on the morphology of *J. scopulorum* across different irrigation and shading intensities. The findings of this study aim to bridge the knowledge gap and contribute to the research on *J. scopulorum* nursery production for urban landscaping. By elucidating the factors that influence the production of high-quality seedlings, this research can inform large-scale nursery practices, thereby enhancing the understanding of optimal seedling characteristics and promoting cost-effective production.

2. Materials and Methods

2.1. Study Site and Greenhouse Setting

This research was carried out at the two-greenhouse (24 m × 8 m), located in the Agricultural Experimental Field, College of Agriculture and Life Science Chungnam National University, Daejeon, South Korea (36° 22' 00" N 127° 21' 00" E) from June to September 2023. The study site's climate is temperate, with cold winters and humid summers. Environmental data was obtained using the HOBO data logger (U23 Pro v2, USA) installed in every treatment pot shown in **Table 1**.

Table 1. Daily mean moisture, relative humidity, temperature under different shading (0%, 35%, and 55%), and irrigation intensities (200 ml, 400 ml, and 800 ml) at the greenhouse from June to September 2023

Shade/Irrigation	0%			35%			55%		
	200 ml	400 ml	800 ml	200 ml	400 ml	800 ml	200 ml	400 ml	800 ml
Moisture (m^3/m^3)	0.13	0.27	0.32	0.10	0.28	0.36	0.11	0.32	0.30
Relative Humidity (%)		74			75			75	
Temperature (°C)		27			27			27	

A plastic pallet (1,300 × 1,100 × 130 mm^3) separated the seedling container from the soil. The distance between the seedlings containers was 0.12 m × 0.75 m. Artificial growing media consisting of coco peat (68%), peat moss (14%), pearlite (7%), zeolite (4%), and vermiculite (6%) were used in this study (Landis et al. 1989). The chemical properties of the growing media are shown in **Table 2**.

Table 2. Soil chemical properties of the growing media

Bed soil	pH	EC (dS/m)	OM (%)	A-P (mg/L)	T-N (mg/L)	NO_3 -N (mg/L)	NH_4-N (mg/L)	C/N	CEC (cmol +/L)	Ex-Na (cmol +/L)	Ex-Ca	Ex-K	Ex-Mg
1	5.54	0.60	57.61	385	268	240	15.62	1183	53.93	5.21	20	14.33	14.4
2	5.50	0.60	57.12	389	295	221	12.42	1066	49.95	4.61	19.41	13.22	12.71
3	5.52	0.53	60.77	407	285	231	22.44	1175	51.88	4.92	19.75	13.72	1.48

Note: Bed soil is the media used, and the number is the number of times it was analyzed.

2.2. Seedling Preparation

Two varieties (Blue Angel and Blue Heaven) of *J. scopulorum* were used in this study and obtained from Cheonan, Korea. The *J. scopulorum* was aged 1–2 years from a grafted seedling that had characteristics of 6.93 ± 0.38 cm height and 3.44 ± 0.156 mm root collar diameter. Before treatment imposition, seedlings were first acclimatized for around three weeks, in which all seedlings were watered daily. Seedlings were carefully transplanted from a nursery pot into a 192 mm × 215 mm seedling container.

2.3. Experiment Design

In this study, completely randomized design (CRD) was used to analyze (1) the shading intensity (0%, 35%, and 55% of full sunlight), (2) the irrigation (200, 400, and 800 ml per container 3-5 days intervals), and (3) the biochar (0% and 20%) with fertilizer (0, 150, and 300 ppm) that was combined as amendment factor. The combination of shading X and irrigation X amendments was designed as a split plot.

A total of 432 Blue Angel and Blue Heaven seedlings were used in the study. Polyvinyl phytotron was used with 0%, 35%, and 55% light intensity transparency. All sides of the greenhouse were covered. Shading intensity was quantified using an illuminance meter (TM-202, Tenmars Electronics Co., Ltd., Taiwan) to assess shading levels across different temporal parameters, including months, seasons, and hours. The measurements were conducted inside and outside the greenhouse to capture variations in light intensity. The natural light intensity outside the greenhouse was considered the reference point and recorded at 100%. Where 0%, 35%, and 55% shading, the illuminance meter recorded 90%, 54%, and 22% light blocking compared to the outside. Manual irrigation was performed every 3–5 days, based on soil moisture measurements taken with a portable moisture analyzer. Moisture was measured every two days to ensure a similar irrigation pattern in shaded areas. Watering was conducted if the moisture content was 10%, 20%, and 30%. Peter Professional 20-20-20 (N:P:K) was used as fertilizer mixed with 15 liters of water based on N concentration. Both fertilizer and irrigation were applied manually. Rice husk biochar was used, which pyrolyzed at 500–650°C. The chemical properties of the biochar are shown in **Table 3**. The ratio of biochar to soil was 1:5.

Table 3. Biochar properties of rice husk

Properties	pH	EC (ds m^{-1})	C (%)	N (g Kg^{-1})	P (g. kg^{-1})	K (g Kg^{-1})	Na (g Kg^{-1})	Ca (g Kg^{-1})	Mg (g Kg^{-1})
Value	6.3 (0.3)	0.394 (0.147)	45.4 (0.1)	5.7 (0.1)	12.05 (0.08)	2.68 (-0.1)	7.34 (0.59)	158.0 (7.1)	10.38 (0.62)

Note: Numbers in the parentheses are standard errors.

2.4. Data Collection

Each plant variety's height and root collar diameter were measured at the beginning of all experimental treatments. At the end of the experiment, plant height and root collar diameter were recorded to determine relative growth performance. Seedling height was measured from the ground to the base of the leaves of the longest stem by the folding ruler, and root collar diameter was measured at 1 cm above the ground by an electric caliper. The data collection interval was four months, from June to September 2023. The relative growth rate was calculated by using Equation 1.

$$Relative\ growth\ rate\ (\%) = \frac{(Final - Initial)}{Initial} \times 100 \quad (1)$$

After the experiment ended in September 2023, all seedlings were harvested and divided into stems, leaves, and roots. The roots were rinsed with tap water to remove soil particles without damaging the fragile fine roots. The collected aboveground biomass (stem and leaf) and below-ground biomass (root) of plant samples were oven-dried at 65°C for 72 hours and weighed to estimate biomass.

2.5. Statistical Analysis

For both cultivars, One-way-ANOVA was performed to investigate significant differences in shade, Irrigation, and amendment; two-way-ANOVA was performed for factor combination was carried out to analyze the primary and interacting effects of the different shading and irrigation on the morphological growth of *J. scopulorum* cultivar for different biochar and fertilization amendment. On the other hand, Tukey's HSD post hoc test was used to compare treatment means at a significance level of 0.05 and 0.01. All statistical analyses were performed using IBM SPSS Statistics (Version 25).

3. Results and Discussion

Shade treatment applied on Blue Angel had significant differences for the root biomass variable. Irrigation was the most influential factor, and significant differences were observed in height, root collar diameter (RCD), and stem and leaf biomass. Amendment and factor combination showed no significant difference in the analysis of any variables. On the other hand, Blue Heaven also showed significant differences in height, stem, RCD, leaf, and root biomass by irrigation treatment, giving all variables significant differences. Furthermore, the height and stem biomass increments were proven to be significantly different by shade treatment. Unlike Blue Angel, amendment treatment gave substantial differences in RCD and root biomass, and the factor combination of shade x amendment was also significant in RCD and root biomass (**Table 4**).

3.1. Morphological Growth Performance of Two J. Scopulorum Cultivars to Factor Analysis

Blue Angel showed a significant shading effect on root biomass and leaf biomass (**Fig. 1**). Seedlings with total sunlight exposure (0%) accumulated the largest root biomass at 4.9 g plant-1 ($p < 0.05$) and leaf biomass at 9.9 g plant-1 ($p < 0.05$). In contrast, maximum height (65.9%) and RCD (90.0%) were noted for completely exposed (0%) and lightly shaded (35%). On the other hand, a significant shading effect was detected on the height, RCD, and leaf biomass of Blue

Heaven ($p < 0.05$ for height; $p < 0.01$ for RCD). At the same time, leaf biomass significantly affected both species.

Table 4. P-value of all factor and factor combinations at different variable

Cultivars			**Blue Angel**					**Blue Heaven**		
Factor	**Height**	**Stem**	**RCD**	**Leaf**	**Root**	**Height**	**Stem**	**RCD**	**Leaf**	**Root**
Shade	0.12	0.06	0.11	0.06	**0.04***	**0.01***	**0.00***	0.10	0.07	0.07
Irrigation	**0.02***	**0.01***	**0.02***	**0.00***	0.39	**0.01***	**0.00***	**0.01***	**0.00***	**0.04***
Amendments	0.09	0.62	0.12	0.64	0.50	**0.00***	0.15	**0.03***	0.78	0.12
Shade X amendments	0.82	0.97	0.28	0.56	0.67	0.33	0.81	**0.00***	0.47	**0.03***
Irrigation X amendments	0.91	0.13	0.69	0.62	0.82	0.86	0.42	0.26	0.50	0.83

Note: Bold value shows a significant difference at 95% (<0.05): * and 99% (<0.01): **.

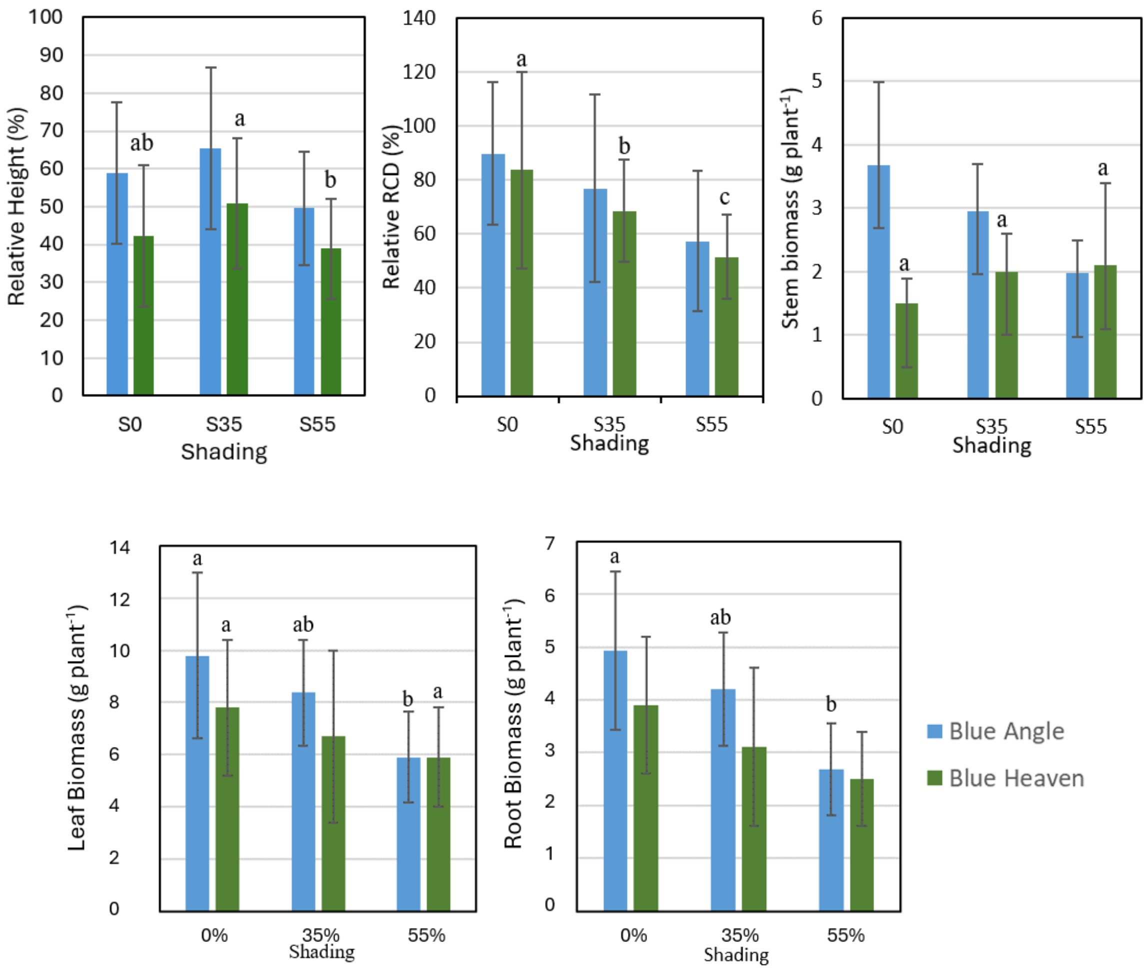

Fig. 1. The influence of shade on morphological growth performance of two *J. scopulorum* cultivars within a treatment denotes significant differences across levels via Tukey's HSD test: 0% is full sunlight, 35% is 35% shade, and 55% is 55% shade. Whiskas is the standard error (n = 4). The letter above the bars shows the different groups at a 95% significant level. Bars without letters show no significant difference at a 95% significant level.

Cultivars illustrated a similar pattern with increasing shading growth decrease. The finding is supported by Park et al. (2023), stating that plants perform better morphologically and physiologically in direct sunlight to moderate shading. Generally, *J. scopulorum* is known to thrive in bare areas and arid, rocky mountain slopes, and plants that can grow in sunlit settings may not survive or succeed in shaded conditions (Coomes et al. 2009; Kupers et al. 2019). Sunlight is used for photosynthesis to transform light energy into chemical energy, which is then utilized to create essential nutrients, growth, and development. Sevillano et al. (2016) showed that light treatments considerably impacted root mass, with seedlings in full sunshine averaging higher values than seedlings in severe shade. In this study, height growth was higher in moderate (35%) shading, which is consistent with Wang et al. (2023) seedlings treated with 40% shade (L2) showed the maximum net growth.

On the other hand, Youn et al. (2021) observed that seedlings planted in full sunlight exhibited more significant aboveground biomass growth than shaded treatment in *Adenophora divaricate*. Huang et al. (2020) showed that the underground biomass (root) of *P. pygmaeus* plants was 1.11–1.95 times more than the aboveground biomass during the growing season under full sunlight. Moreover, in this study high level of shading (55%), *Leucocoprinus birnbaum* fungus grew in 55% shading (El-Fallal et al. 2019); on the other hand, in a medium level of shading and full sunlight, it did not show disease or fungus. This indicates that higher shading for *J. scopulorum* is susceptible to insects and diseases and needs more research. Irrigation significantly affected the morphological traits of the two *J. scopulorum* cultivars, except for the root biomass of Blue Angel, whose values remained homogenous with increasing irrigation intensities (**Fig. 2**).

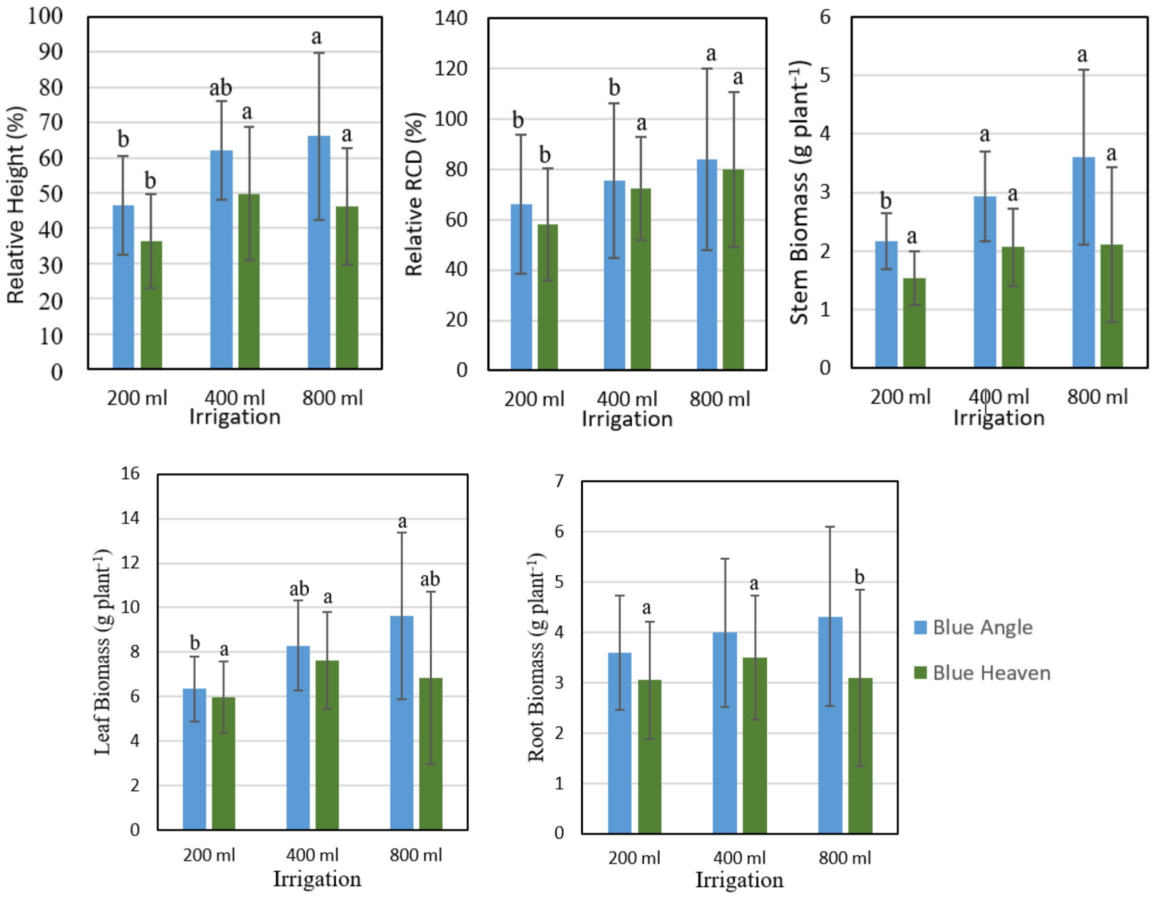

Fig. 2. The influence of irrigation on morphological growth performance of two *J. scopulorum* cultivars within a treatment. Whiskas is the standard error (n = 4)). The letter above the bars shows the different groups at a 95% significant level. Bars without letters show no significant difference at a 95% significant level.

The morphological growth pattern of Blue Angel was homogenous across fertilization and biochar application levels (**Fig. 3**). Blue Heaven showed maximum height (56.1%) and foliar biomass (8.2 g plant^{-1}) without biochar and fertilizer-abundant (300 ppm) conditions ($p < 0.01$ for height; $p < 0.05$ for foliar biomass). In contrast, combinations of 20% biochar × 0 ppm fertilizer and 20% biochar × 150 ppm fertilizer caused minor height and foliar biomass growth among Blue Heaven seedlings. Other morphological parameters observed in Blue Heaven remained unresponsive to fertilizer and biochar treatments ($p = 0.12–0.78$). So, the higher the fertilizer, the more significant the growth compared to the lower level without biochar. According to Schulz et al. (2013), using biochar in combination with organic fertilizer can stimulate plant growth and improve fertilizer efficiency. Adding biochar to sandy loam soil improves its ability to hold water and may make more water accessible for crop use (Kongthod et al. 2015).

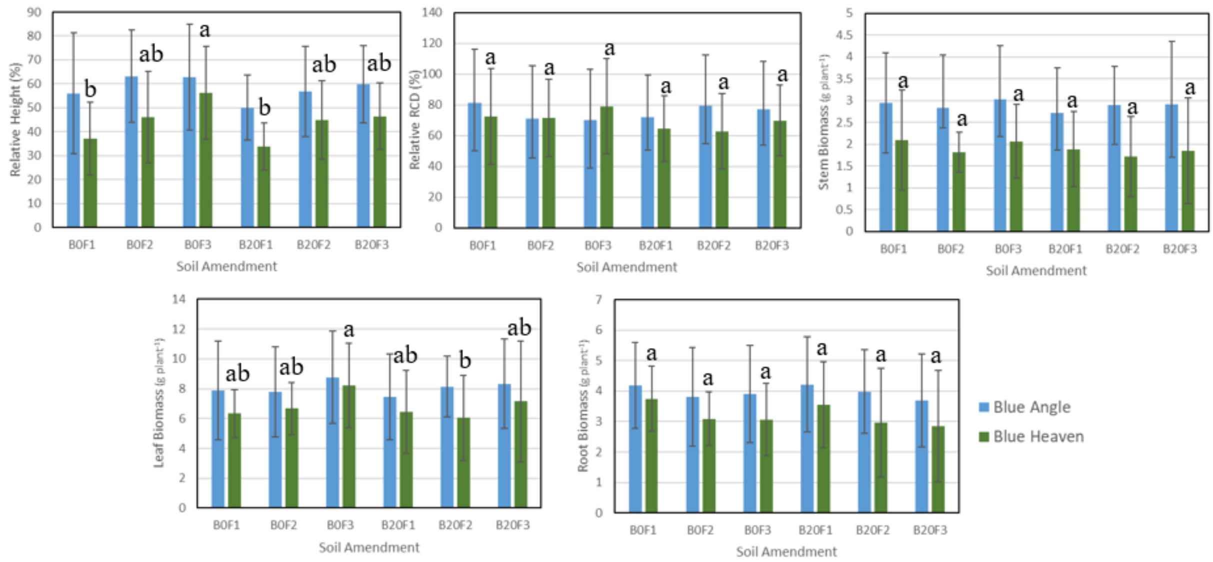

Fig. 3. The influence of soil amendments on morphological growth performance of two *J. scopulorum* cultivars indicate statistical differences across treatment groups: B0 is 0% biochar, B20 is 20% biochar, F1 is 0 ppm fertilizer, F2 is 150 ppm fertilizer, and F3 is 300 ppm fertilizer. Whiskas is the standard error (n = 4)). The letter above the bars shows the different groups at a 95% significant level. Bars without letters show no significant difference at a 95% significant level.

Biochar has absorbing and holding characteristics that help hold fertilizer for a long time. However, depending on the crop and kind of biochar, biochar has been shown to have positive, neutral, or even negative impacts on plant development and output (Kavitha et al. 2018). In this study, biochar treatment showed higher growth than biochar treatments. Biochar function depends on the feedstock type, pyrolysis temperature, stem activation ash, and pH, but the presence of high phytotoxic chemicals and adding biochar can negatively impact plant growth (Jaiswal et al. 2014). Liu et al. (2022) results also indicated that a without biochar (0 t/ha) together with moderate fertilizer increased plant growth. Biochar did not boost plant development in this experiment, and it did not harm the plant either. This is not an uncommon conclusion; Spokas et al. (2012) discovered that around 30% of the research examined showed no effect of biochar on plant growth. Although biochar individuals did not impact growth, it could have affected physio-chemical properties that need to be tested in future experiments.

3.2. Morphological Growth Performance of Two J. scopulorum Cultivars to Bio-Fertilizer at Different Shade and Irrigation Levels

The effect of soil amendments (biochar and fertilizer application) on the foliar and root biomass of Blue Heaven varied by shading intensity (**Fig. 4**). Foliar biomass was highest at 0% shade, 20% biochar, and 300 ppm fertilizer levels (9.7 g plant^{-1}). The opposite was held at 35% shading, 20% biochar, and 150 ppm fertilizer levels. Meanwhile, 35% shading × 20% biochar × 0 ppm fertilizer and 35% shading × 20% biochar × 300 ppm fertilizer combinations generated the highest and lowest root biomass values, respectively.

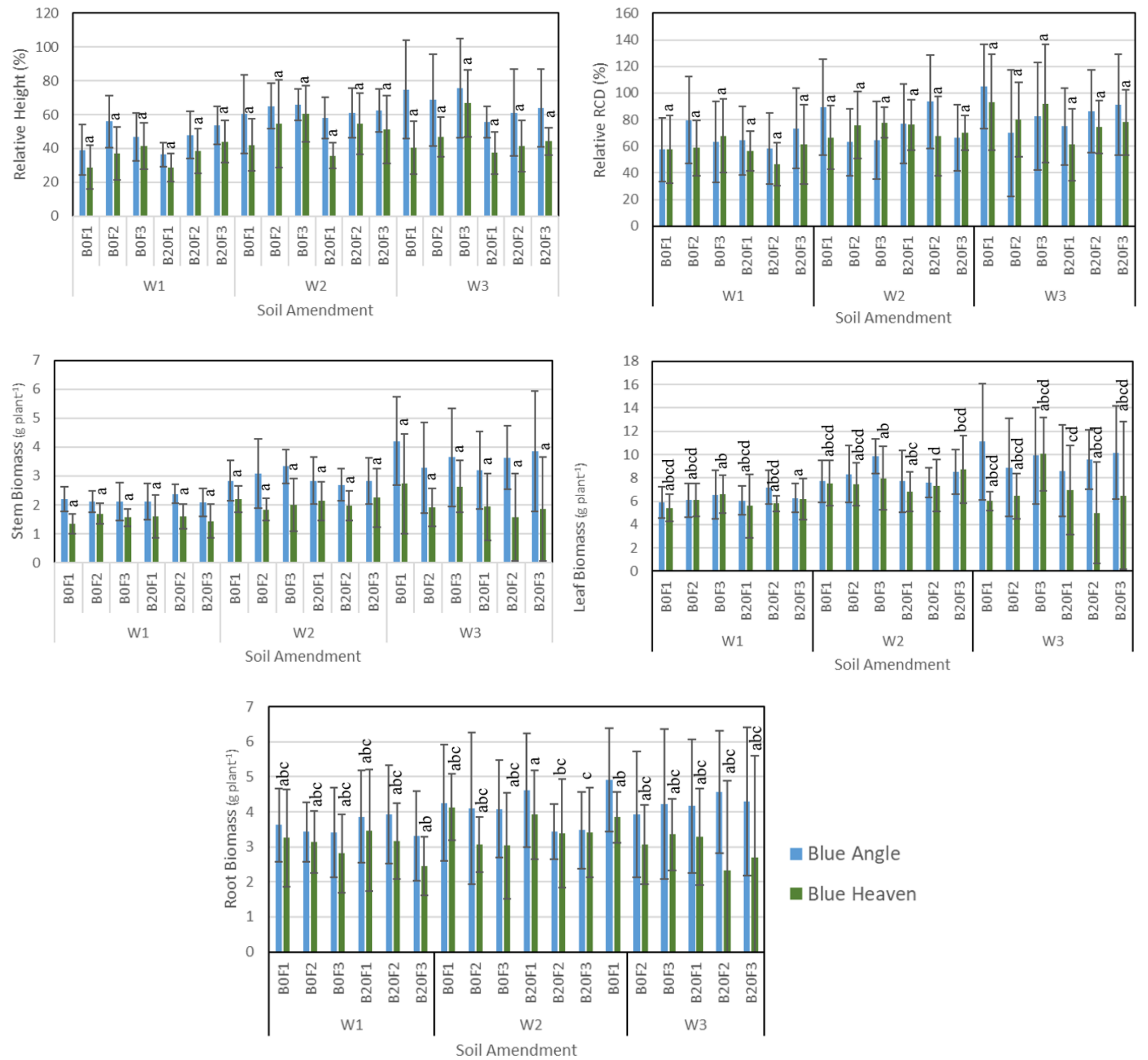

Fig. 4. Morphological growth performance of two *J. scopulorum* cultivars to soil amendment at different shade levels (Different lowercase letters indicate statistical differences across treatment groups), B0 is 0% biochar, B20 is 20% biochar, F1 is 0 ppm fertilizer, F2 is 150 ppm fertilizer, F3 is 300 ppm fertilizer, S0 is full sunlight, S35 is 35% shade, and S55 is shade 55%. Whiskas is the standard error (n = 4). The letter above the bars shows the different groups at a 95% significant level. Bars without letters show no significant difference at a 95% significant level.

Unlike Blue Heaven, no significant shade × fertilizer × biochar interactions were detected for Blue Angel ($p = 0.27–0.97$). Therefore, it is noticeable that growth decreases with increasing the shading intensity. This result is supported by a meta-analysis that using biochar with N fertilizer boosts N use efficiency and agricultural output by 10–12.0% (Liu et al. 2022). Studies by Wang et al. (2023) findings show that combining N fertilizer with a mild amount of biochar under irrigation considerably improves crop morphological and physiological traits.

On the other hand, biomass production increased with the enhancement of silvicultural practices (Noulèkoun et al. 2017). Research by Mckinley and Van Auken (2005) has shown that the availability of additional nutrients in ambient light conditions significantly influences the growth of junipers. Conversely, growth rates were intermediate when nutrients were absent in ambient light and vice versa. This experiment also showed a considerably higher foliar and root biomass in ambient or moderate shade, with biochar in contrasting fertilizer conditions in Blue Heaven. However, this study showed that the fertilizer level varied regardless of treatments. This is endorsed by Pinno et al. (2012), stating that conifer fertilization frequently produces unpredictable growth responses at different locales. In addition, Simiele et al. (2022) also stated that 20% biochar amendment with soil enhances plant growth compared to control.

4. Conclusions

High-quality *J. scopulorum* seedlings are essential for successful landscape establishment and greening. Optimizing shade, irrigation, and soil amendment practices can enhance seedling growth, reduce production costs, and contribute to the sustainability of landscape projects. The result showed that biochar and higher fertilizer significantly increased the height and root collar diameter growth of *J. scopulorum,* both cultivars Blue Angel and Blue Heaven, particularly those grown in high levels of irrigation (400–800 ml) and low shading intensities (0–35%). Both cultivars' morphological growth was significantly impacted by irrigation and shade levels, and these factors also positively interacted with soil amendments (fertilizer and biochar). This protocol provides a foundation for continuously producing high-quality *J. scopulorum* seedlings. However, further research is warranted to elucidate the complex physiological and chemical properties influencing seedling development and performance. Future studies should focus on nursery and field conditions, investigating the interactive effects of integrating physiological and chemical attributes to optimize *J. scopulorum* seedling production.

Acknowledgments

This research was carried out with the support of the "R&D Program for Forest Science Technology (Project No.2021379B10-2323-BD02)" provided by the Korea Forest Service (Korea Forest Promotion Institute).

References

Bai, S. H., Omidvar, N., Gallart, M., Kämper, W., Tahmasbian, I., Farrar, M. B., Singh, K., Zhou, G., Muqadass, B., Xu, C., Koech, R., Li, Y., Nguyen, T. T. N., and Van Zwieten, L. 2022. Combined Effects of Biochar and Fertilizer Applications on Yield: A Review and Meta-Analysis. *Science of the Total Environment* 808: 152073. DOI:

10.1016/j.scitotenv.2021.152073

Basso, A. S., Miguez, F. E., Laird, D. A., Horton, R., and Westgate, M. 2013. Assessing Potential of Biochar for Increasing Water-Holding Capacity of Sandy Soils. *GCB Bioenergy* 5(2): 132–143. DOI: 10.1111/gcbb.12026

Bhadouria, R., Singh, R. P., Srivastava, P., and Raghubanshi, A. S. 2016. Understanding the Ecology of Tree-Seedling Growth in A Dry Tropical Environment: A Management Perspective. *Energy, Ecology and Environment* 1(5): 296–309. DOI: 10.1007/s40974-016-0038-3

Cho, S., Byambadorj, S., Nyam-Osor, B., and Kim, H. 2019. Comparison of Water Use Efficiency and Biomass Production in 10-year-old *Populus sibirica* and *Ulmus pumila* Plantations in Lun Soum, Mongolia. *Forest Science and Technology* 15(3): 147–158. DOI: 10.1080/21580103.2019.1634646

Coomes, D. A., Künstler, G., Canham, C. D., and Wright, E. F. 2009. A Greater Range of Shade-Tolerance Niches in Nutrient-Rich Forests: An Explanation for Positive Richness–Productivity Relationships?. *Journal of Ecology* 97(4): 705–717. DOI: 10.1111/j.1365-2745.2009.01507.x

Di Lonardo, S., Baronti, S., Vaccari, F. P., Albanese, L., Battista, P., Miglietta, F., and Bacci, L. 2017. Biochar-Based Nursery Substrates: The Effect of Peat Substitution on Reduced Salinity. *Urban Forestry and Urban Greening* 23: 27–34. DOI: 10.1016/j.ufug.2017.02.007

El-Fallal, A. A., El-Sayed, A. K. A., and El-Gharabawy, H. M. 2019. *Podaxis pistillaris* (L.) Fr. and *Leucocoprinus birnbaumii* (Corda) Singer; New Addition to Macrofungi of Egypt. *Egyptian Journal of Botany* 59(2): 413–423. DOI: 10.21608/ejbo.2019.5990.1255

El-Juhany, L. I., and Al-Shehri, A. M. S. 2020. The Response of *Juniperus procera* Seedlings to Irrigation Water Deficit. *Middle-East Journal of Scientific Research* 28(5): 448–456. DOI: 10.5829/idosi.mejsr.2020.448.456

Evren, O. H., and Kaya, N. 2020. A Comparison of Some Physical and Chemical Soil Characteristics of Crimean Juniper (*Juniperus excelsa* M. Bieb) Populations in Turkey. *Journal of Tekirdag Agricultural Faculty* 17(1): 37–52. DOI: 10.33462/jotaf.556666

Farsi, K. A., Cameron, R., Hitchmough, J., and Lupton, D. 2017. Assessing the Effects of Drought and Temperature on the Establishment of *Juniperus seravschanica* Saplings in Northern Oman. *Sibbaldia: The Journal of Botanic Garden Horticulture* 14: 37–53. DOI: 10.24823/sibbaldia.2016.187

Hernandez, J. O., Combalicer, M. S., Umali, A. G. A., and Maldia, L. S. J. 2024. Effects of Decapitation, Water-Deficit Stress, and Pot Size on Morpho-Anatomy and Physiology of Pterocarpus indicus. *Jurnal Sylva Lestari* 12(1): 113–131. DOI: 10.23960/jsl.v12i1.821

Huang, W., Olson, E., Wang, S., and Shi, P. 2020. The Growth and Mortality of *Pleioblastus pygmaeus* Under Different Light Availability. *Global Ecology and Conservation* 24: e01262. DOI: 10.1016/j.gecco.2020.e01262

Huxman, T. E., Wilcox, B. P., Breshears, D. D., Scott, R. L., Snyder, K. A., Small, E. E., Hultine, K., Pockman, W. T., and Jackson, R. B. 2005. Ecohydrological Implications of Woody Plant Encroachment. *Ecology* 86: 308–319. DOI: 10.1890/03-0583

Jaiswal, A. K., Elad, Y., Graber, E. R., and Frenkel, O. 2014. *Rhizoctonia solani* Suppression and Plant Growth Promotion in Cucumber as Affected by Biochar Pyrolysis Temperature, Feedstock and Concentration. *Soil Biology and Biochemistry* 69: 110–118. DOI:

10.1016/j.soilbio.2013.10.051

Kavitha, B., Reddy, P. V. L., Kim, B., Lee, S. S., Pandey, S. K., and Kim, K. 2018. Benefits and Limitations of Biochar Amendment in Agricultural Soils: A Review. *Journal of Environmental Management* 227: 146–154. DOI: 10.1016/j.jenvman.2018.08.082

KFS. 2016. *Statistical Yearbook of Forestry 2016 Korea Forest Service*. Korea Forest Service, Daejeon, Korea.

Kongthod, T., Thanachit, S., Anusontpornperm, S., and Wiriyakitnateekul, W. 2015. Effects of Biochars and Other Organic Soil Amendments on Plant Nutrient Availability in an Ustoxic Quartzipsamment. *Pedosphere* 25(5): 790–798. DOI: 10.1016/s1002-0160(15)30060-6

Kupers, S. J., Wirth, C., Engelbrecht, B. M. J., Hernández, A., Condit, R., Wright, S. J., and Rüger, N. 2019. Performance of Tropical Forest Seedlings Under Shade and Drought: An Interspecific Trade-off in Demographic Responses. *Scientific Reports* 9(1): 18784 . DOI: 10.1038/s41598-019-55256-x

Landis, T. D. 1989. *Irrigation and Water Management*. In: Landis, T. D., Tinus, R. W., McDonald, S. E., and Barnett, J. P. (eds) The Container Tree Nursery Manual Vol. 4. Agric. Handbook, USDA Forest Service, Washington, D.C.

Lee, K., Hong, J. W., Kim, J., Jo, S., and Hong, J. 2021. Traces of Urban Forest in Temperature and CO_2 Signals in Monsoon East Asia. *Atmospheric Chemistry and Physics* 21(23): 17833–17853. DOI: 10.5194/acp-21-17833-2021

Liu, M., Linna, C., Ma, S., Ma, Q., Guo, J., Wang, F., and Wang, L. 2022. Effects of Biochar with Inorganic and Organic Fertilizers on Agronomic Traits and Nutrient Absorption of Soybean and Fertility and Microbes in Purple Soil. *Frontiers in Plant Science* 13: 871021. DOI: 10.3389/fpls.2022.871021

Liu, Z., Dugan, B., Masiello, C. A., and Gonnermann, H. M. 2017. Biochar Particle Size, Shape, and Porosity Act Together to Influence Soil Water Properties. *PLOS ONE* 12(6): e0179079. DOI: 10.1371/journal.pone.0179079

Masiello, C. A., Dugan, B., Brewer, C. E., Spokas, K. A., Novak, J. M., Liu, Z., and Sorrenti, G. 2015. *Biochar Effects on Soil Hydrology*. In: Lehmann, J., Joseph, S. (eds) Biochar for Environmental Management: Science, Technology and Implementation, 2nd ed. Earthscan, Routledge, London.

Mathaux, C., Mandin, J., Oberlin, C., Édouard, J., Gauquelin, T., and Guibal, F. 2016. Ancient Juniper Trees Growing on Cliffs: Toward A Long Mediterranean Tree-Ring Chronology. *Dendrochronologia* 37: 79–88. DOI: 10.1016/j.dendro.2015.12.005

McKinley, D. C., and Van Auken, O. W. 2005. Influence of Interacting Factors on the Growth and Mortality of Juniperus Seedlings. *American Midland Naturalist* 154(2): 320–330. DOI: 10.1674/0003-0031(2005)154

Noulèkoun, F., Khamzina, A., Naab, J. B., and Lamers, J. P. 2017. Biomass Allocation in Five Semi-Arid Afforestation Species is Driven Mainly by Ontogeny Rather Than Resource Availability. *Annals of Forest Science* 74: 1–12. DOI: 10.1007/s13595-017-0676-4

Nowak, D. J., Hirabayashi, S., Doyle, M., McGovern, M. E., and Pasher, J. 2018. Air Pollution Removal by Urban Forests in Canada and Its Effect on Air Quality and Human Health. *Urban Forestry and Urban Greening* 29: 40–48. DOI: 10.1016/j.ufug.2017.10.019

Park, S., Lee, J. H., and Nam, S. Y. 2023. An Analysis of the Growth and Photosynthetic Responses of Potted *Veronica pusanensis* Y. N. Lee according to the Shading Levels. *Journal of People, Plants, and Environment* 26(3): 219–231. DOI:

10.11628/ksppe.2023.26.3.219

Pinno, B. D., Lieffers, V. J., and Landhäusser, S. M. 2012. Inconsistent Growth Response to Fertilization and Thinning of Lodgepole Pine in the Rocky Mountain Foothills is Linked to Site Index. *International Journal of Forestry Research* 2012: 1–7. DOI: 10.1155/2012/193975

Rawat, Y. S., and Everson, C. S. 2013. Availability and Use of Willow Species in Representative Cold Desert Areas of Northwestern Himalaya, India. *Journal of Mountain Science* 10(3): 472–481. DOI: 10.1007/s11629-013-2687-4

Royo, A., Gil, L., and Pardos, J. A. 2001. Effect of Water Stress Conditioning on Morphology, Physiology and Field Performance of *Pinus halepensis* Mill. Seedlings. *New Forests* 21: 127–140. DOI: 10.1023/a:1011892732084

Schulz, H., Dunst, G., and Glaser, B. 2013. Positive Effects of Composted Biochar on Plant Growth and Soil Fertility. *Agronomy for Sustainable Development* 33(4): 817–827. DOI: 10.1007/s13593-013-0150-0

Schutzki, R. E. 2005. *A Guide for the Selection and Use of Plants in the Landscape*. Michigan State University Extension, East Lansing.

Scianna, J., Majerus, M. E., and Holzworth, L. K. 2000. *Bridger-Select Rocky Mountain Juniper, a Conservation Plant for Montana and Wyoming*. USDA NRCS-Plant Materials Center, Montana.

Sevillano, I., Short, I., Grant, J., and O'Reilly, C. 2016. Effects of Light Availability on Morphology, Growth and Biomass Allocation of *Fagus sylvatica* and *Quercus robur* Seedlings. *Forest Ecology and Management* 374: 11–19. DOI: 10.1016/j.foreco.2016.04.048

Simiele, M., Argentino, O., Baronti, S., Scippa, G. S., Chiatante, D., Terzaghi, M., and Montagnoli, A. 2022. Biochar Enhances Plant Growth, Fruit Yield, and Antioxidant Content of Cherry Tomato (*Solanum lycopersicum* L.) in a Soilless Substrate. *Agriculture* 12(8): 1135. DOI: 10.3390/agriculture12081135

Spokas, K. A., Cantrell, K. B., Novak, J. M., Archer, D. W., Ippolito, J. A., Collins, H. P., Boateng, A. A., Lima, I. M., Lamb, M. C., McAloon, A. J., Lentz, R., and Nichols, K. A. 2012. Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration. *Journal of Environmental Quality* 41(4): 973–989. DOI: 10.2134/jeq2011.0069

Syuhada, A. B., Shamshuddin, J., Fauziah, C. I., Rosenani, A. B., and Abdu, A. 2016. Biochar as Soil Amendment: Impact on Chemical Properties and Corn Nutrient Uptake in A Podzol. *Canadian Journal of Soil Science* 96(4): 400–412. DOI: 10.1139/cjss-2015-0044

Viezzer, J., Schmidt, M. A. R., Dos Reis, A. R. N., Freiman, F. P., De Moraes, E. N., and Biondi, D. 2022. Restoration of Urban Forests to Reduce Flood Susceptibility: A Starting Point. *International Journal of Disaster Risk Reduction* 74: 102944. DOI: 10.1016/j.ijdrr.2022.102944

Wang, R., Ma, J., Huang, R., Wang, Y., Jiang, Y., Ling, Y., Yang, J., Liang, H., Liu, X., and Liao, N. 2023. The Effects of Shading on the Photosynthetic Performance of Endangered Plant *Horsfieldia hainanensis* Seedlings. *Forests* 15(1): 3. DOI: 10.3390/f15010003

Wolf, K. L., Lam, S., McKeen, J., Richardson, G. R. A., Van Den Bosch, M., and Bardekjian, A. C. 2020. Urban Trees and Human Health: A Scoping Review. *International Journal of Environmental Research and Public Health* 17(12): 4371. DOI: 10.3390/ijerph17124371

WHO. 2012. *Health Indicators of Sustainable Cities in the Context of the Rio+20 UN Conference* *on Sustainable Development*. World Health Organization (WHO), Geneva, Switzerland.

Youn, W. B., Hernandez, J. O., and Park, B. B. 2021. Effects of Shade and Planting Methods on the Growth of *Heracleum moellendorffii* and *Adenophora divaricata* in Different Soil Moisture and Nutrient Conditions. *Plants* 10(10): 2203. DOI: 10.3390/plants10102203

Yu, O. Y., Raichle, B., and Sink, S. 2013. Impact of Biochar on the Water Holding Capacity of Loamy Sand Soil. *International Journal of Energy and Environmental Engineering* 4: 1–9. DOI: 10.1186/2251-6832-4-44