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Effects of shading and fertilizer treatments on the growth characteristics of *Chamaecyparis obtusa* (S. et Z.) Endlicher seedlings

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ABSTRACT

Chamaecyparis obtusa is increasing the main reforestation species in the warmer southern part of the Republic of Korea because of its resistance to climate warming and economic value for timber. In this study, we investigated the growth response of *Chamaecyparis obtusa* 2-0 container seedlings to combined artificial shading (full sunlight, 35%, 55%, and 75%) and fertilization (no fertilization, 0.5 g/L, 1.0 g/L 1.5 g/L, 2.0 g/L, 3.0 g/L) treatments. Seedlings treated with 1.0 g/L fertilization and in full sunlight condition showed the highest height growth while seedlings treated with 0.5 g/L fertilization and in full sunlight condition showed the highest growth of root collar diameter. Seedlings treated with 1.0 g/L fertilization and in full sunlight condition showed the highest total dry weight while those treated with 0.5 g/L, 1.0 g/L and 1.5 g/L fertilization and in full sunlight condition and 0.5 g/L fertilization in 35% artificial shading showed the highest Height/Root collar diameter ratio. In addition, seedlings treated with 1.0 g/L fertilization and in full sunlight condition showed the highest seedling quality index. In general, the fertilization treatment effects on seedling growth characteristics were appreciably significantly different across the shading treatment conditions. The magnitude of the differences in the interaction effect of the fertilization treatments is higher in lower than in higher shading treatment conditions. The results suggest that 1.0 g/L seedling fertilization growing in full sunlight condition is the most appropriate nursery treatment level for producing superior quality *Chamaecyparis obtusa* 2-0 container seedlings. The suggested optimum artificial shading and fertilizer treatments level can be used as preliminary data for producing superior seedlings *Chamaecyparis obtusa* 2-0 container seedlings capable of achieving sustained reforestation and landscape restoration success in the southern part of the Republic of Korea and similar locations with warming climatic and conditions.

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Chamaecyparis obtusa; fertilization concentrations; reforestation; shading conditions; seedling growth characteristics; seedling quality index

Introduction

Large-scale reforestation projects of over 20,000 ha per year are currently carried out in the Republic of Korea and the reforestation area cover is being expanded to 30,000 ha per year with the goal to cultivate commercial forests and sustainable resources (KFS 2013). Needled-leaf evergreen tree species account for approximately 47.6% of the annual reforestation area cover in the Republic of Korea. *Chamaecyparis obtusa* of the cypress family *Cupressaceae Chamaecyparis* is the highest planted of the needled-leaf evergreen tree species and is only second to *Pinus densiflora* as the tree species that account for the largest reforestation area cover in the Republic of Korea. *Chamaecyparis obtusa* is the main reforestation species in the southern part of the Republic of Korea since 1904 when it was first introduced from Japan (Lee 2003; KFS 2020) due to its tolerance to average, medium moisture, full sun to part shade and low maintenance requirement. Thus, it has been primarily selected as the reforestation tree species for climate change mitigation and timber utilization because it has excellent quality. In addition, its recently proven unique antibacterial property has prompted increasing public interest and demand on *Chamaecyparis obtusa* species reforestation for the expansion of forest healing, cultural and recreation activities (Choi et al. 2012; KFS 2014). Furthermore, because the warmth index of the Republic of Korea has increased along with the changing climate, and has expanded the vegetative area limit of tree species for the warm temperate zone, it is expected that the reforestation area of *Chamaecyparis obtusa* in the Republic of Korea will be also expanded in the future (Park et al. 2010b).

Currently, the cultivation and reforestation of *Chamaecyparis obtusa* are carried out in the Republic of Korea based on the bare-root seedling cultivation and planting system in the form of 1-1, 1-1-1, 1-1-2 or 1-2-2, and the production of container seedlings began in 2009 (Song et al. 2012). However, the bare-root

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Table 1. Physical and chemical properties of the bed soil in each treatment facility.

Properties	EC (dS/m)	pH (1: 5, v/v)	OM (%)	NH^{4+}–N (mg/ℓ)	NO_3^-–N (mg/ℓ)	Av. P_2O_5 (mg/ℓ)	CEC (cmol $^+$/ℓ)
Experiment	1.2	5.5 ~ 6.5	25 ± 10	250 ± 100	100 ± 50	200 ± 100	8

seedling cultivation system needs to be promptly switched to the cultivation method where the growth environments can be adjusted following damage by frequent occurrences of drought, flooding and frost conditions due to climate change (Kim et al. 2010). The container seedlings are grown in a constrained container condition, so it is very important to provide appropriate growth environments to seedlings (Aghai et al. 2014). Grossnickle (2005) reported that the growth and physiological activity of container seedlings may be limited due to lighting, nutrient and moisture stress conditions, thus appropriate treatments such as fertilization, temperature and watering for each species are essential for producing healthy and good quality seedlings. An increasing number of studies in the Republic of Korea have focused on the appropriate containers and fertilization concentration required for cultivation of *Chamaecyparis obtusa* (e.g. Song et al. 2012; Cho et al. 2014; Jae 2015). However, only a few studies have focused on the growth response of *Chamaecyparis obtusa* container seedlings to combined effects of different light or conversely shading and fertilization concentration conditions.

Therefore, the purpose of this study was to provide preliminary data required for the cultivation of *Chamaecyparis obtusa* container seedlings, which are the main reforestation species in the southern part of the Republic of Korea and whose reforestation area cover expansion is expected to increase in the future. The main aim of the study is to investigate and analyze the growth characteristics and physiological response of *Chamaecyparis obtusa* container seedlings to different combinations of artificial shading and fertilization treatments and suggest the appropriate fertilization level and light condition treatments for producing good quality seedlings that are hardier for climate warming. The study is guided by the hypothesis that the magnitude of the difference of the interaction effect of the fertilization treatments on the seedling growth characteristics is significantly higher in lower than in higher shading treatment conditions.

Materials and methods

Experiment site and testing material

This experiment was carried out inside the glass greenhouse with automatic temperature and ventilation (N 35° 49′ 36″, E 128° 45′ 21″) at Gyeongsan-si, Gyeongsangbuk-do province of the Republic of Korea. The experimental tree species was *Chamaecyparis obtuse* and the seeds were obtained from the Korea Forest Seed and Variety Center, sowed in March 2014 and used for the experiment from March to September 2015. To improve reproducibility, 48 replicates for each treatment and 1,152 samples were used for the experiment. The average height of the seedlings used in the experiment was 14.5 cm and the average root collar diameter is 2.0 mm. A plastic container (KK-SI 320, Shinill Science Inc, Korea) with the volume of 320 ml/unit was used as the test container and the bed soil used was a mixture of cocopeat, peat moss, pearlite and vermiculite (1:1:1:1, v:v:v:v) to enhance seedlings growth and development (Table 1).

Table 2. Growing environmental in each shading treatment facility.

Shading grade	Full sunlight	35 (%)	55 (%)	75 (%)
Average temperature (°C)	25.2	24.2	23.4	23.0
Average relative humidity (%)	67.8	71.5	74.4	76.5

Growth environment conditions

In order to measure the growth environment, HOBO Data Logger (Onset Computer Corporation Inc., USA) was installed into each shading treatment zones. Temperature and relative humidity were measured Every 2 h from April to October 2015. There was a different growth environment in each shading treatment zone caused by shading intensity. It may have affected the seedling growth and it is a limitation of this study.

Shading fertilization treatments

In order to investigate the growth characteristics of seedlings for each shading rate, the shade net was installed inside a glass greenhouse separately into four different shading treatment zones with the different light conditions as follows: the full sunlight, 35% shading, 55% shading, and 75% shading treatments (Table 2). The light intensity of each of the four shading treatment zones was measured and adjusted to an appropriate level using the digital light intensity measuring device (TES-1335, TES Electrical Electronic Corp, Taiwan) and adjusted to an appropriate level for each fertilizer treatment zone.

Fertilization treatments were carried out on 24 container seedlings for each of the four shading treatment zones once a week from 3 April 2015 to 18 September 2015 for a total of 25 times. In each of the four shading treatment zones, six different fertilization concentration treatments were applied, including the no fertilization control treatment (0.0 g), 0.5 g/L, 1.0 g/L, 1.5 g/L, 2.0 g/L, and 3.0 g/L treatment types (Table 2). Multifeed 20 (N:P:K, 20:20:20, Haifa Chemical Co., Israel) water-soluble fertilizer, which is mainly used for the forestry zone cultivation was used. Watering of seedlings was carried out three times a week and one watering treatment was replaced with the fertilization treatment. It should be noted that this study's experimental design involved combined shading and

Table 3. Light intensity and fertilization treatment in each shading treatment facility.

Shading grade	Full sunlight	35 (%)	55 (%)	75 (%)
Light intensity (Klux)	26.39 ± 0.13	16.95 ± 0.10	11.61 ± 0.08	6.55 ± 0.07
Fertilization (g/L)	0.0, 0.5, 1.0, 1.5, 2.0, 3.0	0.0, 0.5, 1.0, 1.5, 2.0, 3.0	0.0, 0.5, 1.0, 1.5, 2.0, 3.0	0.0, 0.5, 1.0, 1.5, 2.0, 3.0

fertilization treatment effects on seedlings' growth characteristics (Table 3) .

Analysis of seedlings growth characteristics

The seeding height and root collar diameter growth were measured for all samples using a digital caliper (ABSOLUTE Digimatic Caliper-500, Mitutoyo, Japan) and a folding ruler on 28 March 2015 before the fertilization and shading treatments were applied to the container seedlings, and on 18 September 2015 when it was expected that the growth of the seedlings was almost stopped. This approach allowed the authors to analyze the effects of artificial shading and fertilization treatments on the growth of *Chamaecyparis obtusa* container seedlings. After the seedling measurement data collection on 18 September 2015, five average growth trees were selected from each treatment zone and oven-dried at 75 °C for 48 h and the dry matter output was measured separately by weight into leaves, stems and roots. In addition, the height/root collar diameter ratio (H/D), dry weight of each seedling part, top dry weight/root dry ratio (T/R), leaf dry weight (LWR), shoot dry weight ratio (SWR), root dry weight ratio (RWR) of the seedlings, and the seedling quality index (SQI) were measured and calculated using the formulas developed by Bayala et al. (2009). These measured parameters were used to determine the healthiness of the monitored seedlings.

°H/D ratio ($cm\ mm^{-1}$) = Height (cm)/Root collar diameter (mm)

°T/R ratio ($g\ g^{-1}$) = Top (leaf + shoot) dry weight (g)/ Root dry weight (g)

°LWR ($g\ g^{-1}$) = Leaf dry weight (g)/Total dry weight (g)

°SWR ($g\ g^{-1}$) = Shoot dry weight (g)/Total dry weight (g)

°RWR ($g\ g^{-1}$) = Root dry weight (g)/Total dry weight (g)

°SQI ($g\ g^{-1}$) = Total dry weight (g)/(H/D ratio + T/ R ratio)

Statistical analysis

Two-way ANOVA was undertaken to determine the effect of shading and fertilization treatments as independent variables on the seedling height and root collar diameter growth, root, shoot, leaves and total mass production, H/D and T/R, ratios, LWR, SWR and RWR, and seedling quality index (SQI). This statistical analysis was undertaken in order to investigate the interaction effects of shading and fertilization treatments on the growth characteristics of *Chamaecyparis obtusa* container seedlings. In case there was a statistically significant difference at $p < 0.05$, the mean value of each item was compared by carrying out Duncan's multiple range *post-hoc* tests. Two-way ANOVA was used to test the magnitude of the differences in the interaction effects of fertilization treatments on the elements of seedling growth characteristics across all the shading or sunlight treatment conditions and the result is presented as figures. The factorial ANOVA tests the interaction effect hypothesis whether the effect of the fertilization treatments on the seedlings' growth characteristics is equal or unequal across all the shading or sunlight treatment conditions. All statistical analyses were completed using the SPSS statistical program (Version 23).

Results and discussion

Growth of seeding height and root collar diameter

The height and root collar diameter growth of *Chamaecyparis obtusa* container seedlings was investigated according to the artificial shading and fertilization treatments (Figure 1(a,b)). All artificial shading treatment types showed significant differences ($p < 0.05$) in seedling height and root collar diameter growth according to the fertilization concentration (Figure 1(a,b)). Seedling height growth was highest at 36.5 ± 1.3 cm for the 1.0 g/L fertilization treatment type in full sunlight condition, and for the root collar, diameter growth was highest at 4.37 ± 0.08 mm for the 0.5 g/L fertilization treatment type in full sunlight condition (Figure 1(a,b)). The no fertilization treatment type in full sunlight condition showed the lowest growth in seedling height at 6.8 ± 0.4 cm, and the 75% shading treatment type with no fertilization treatment showed the lowest growth in root collar diameter at 1.14 ± 0.04 mm (Figure 1(a,b)). Mainly, the 0.5 g/L and 1.0 g/L treatment types showed the best growth response and the no fertilization and 3.0 g/L fertilization treatment types showed relatively lower height and root collar growth response in comparison to the other fertilization treatment types (Figure 1(a,b)). This might be the result of salt accumulation due to excessive fertilization beyond the required nutrients level to sustain the growth of container seedlings, which acts as a limiting factor for the growth of the seedlings (Imo and Timmer 1999).

With respect to the seedlings' growth response to the artificial shading treatments, the highest seedling height growth was observed in the full sunlight treatment condition, followed by 35%, 55% and 75% shading treatments, respectively (Figure 1(a,b)). The result indicated that seedling height growth increased as shading treatment light intensity condition increased, providing supportive evidence that could grow best in conditions of full sunlight. The growth of young

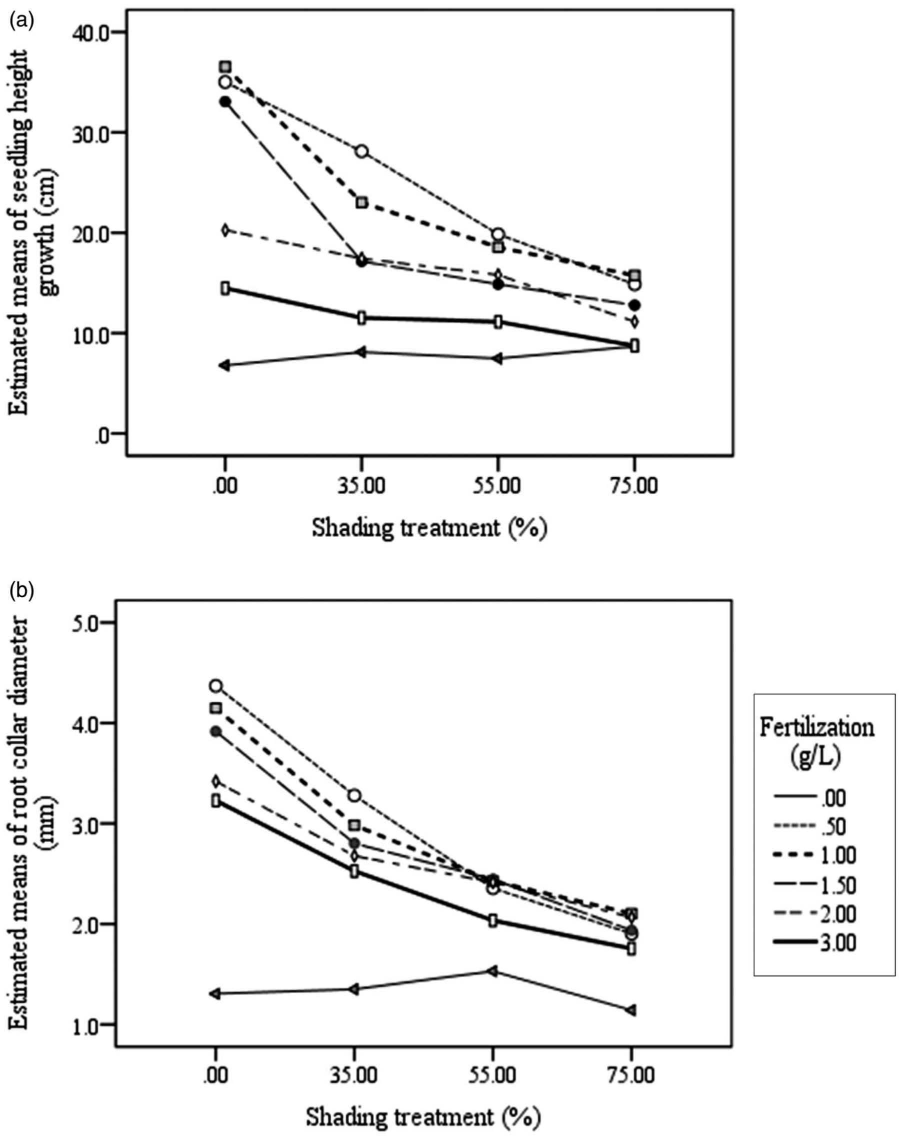

Figure 1. Effects of shading rates and fertilization concentrations on seedling height growth (a) and root collar diameter growth (b) of *Chamaecyparis obtusa* seedlings. Data are estimated marginal means in a two-way ANOVA at a significant level of $p < 0.05$.

Chamaecyparis obtuse tree species in natural environment conditions is negatively affected by a low light condition caused by residual trees in south edge and strip-cutting sites (Hirata et al. 2015). Furthermore, developed understory vegetation at young *Chamaecyparis obtuse* tree stands reduces the tree height growth due to increased shade and restriction of crown expansion, such that the weeding of the understory vegetation increases the tree's exposure to full sun and enhances the recovery of height and DHB growth and the crown projection area of the trees (Hirata et al. 2014). Similarly, in the case of Japanese cedar (*Cryptomeria japonica*) seedlings, the growth in diameter and culm length deteriorates as the relative light intensity becomes lower due to shading treatment (Tanimoto 1975). On the other hand, Cho et al. (2001) reported no significant difference in the growth of Korean fir seedlings in full sunlight condition and those treated with 50%, 30% and 10% artificial shading. These results suggest that the effect of shading on seedling growth varies with tree species so that it is closely related to the shade tolerance of individual tree species.

Meanwhile, seedling height growth clearly decreased with an increase in shading rate and fertilization concentrations treatments, especially with the full sunlight treatment (Figure 1(a)). In the case of seedlings with no fertilization treatment, 75% shading treatment type narrowly showed the highest growth of seedling height (Figure 1(a)). Seedling root collar diameter growth also decreased with an increase in shading rate and fertilization concentration treatments but only in the full sun and 35% shading treatments while no clear relationship was found in the 55% and 75% shading treatment (Figure 1(b)). Furthermore, the seedling height growth varied significantly more than the root collar diameter growth with respect to the shading treatments (Figure 1(a,b)). This result might be attributed to the characteristics of young seedlings to hold favorable positions in conditions of competition for light by promoting more the growth of seedling height than the growth of root collar diameter.

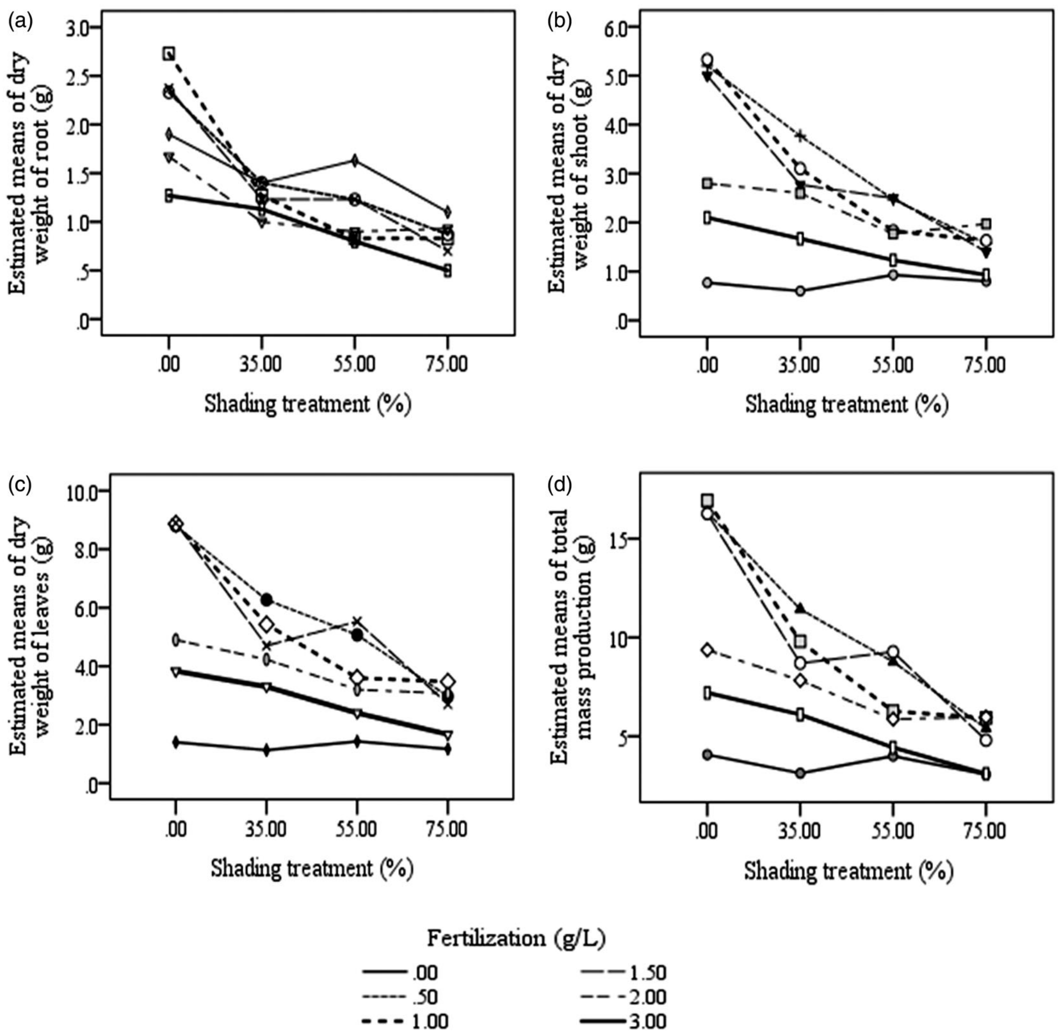

Figure 2. Effects of shading rates and fertilization concentrations on the root (a), shoot (b), leaves (c) and total (d) dry mass production (g) of *Chamaecyparis obtusa* container seedlings. Data are estimated marginal means in a two-way ANOVA at a significant level of $p < 0.05$.

Dry mass production

The dry weight of seedlings is an element that gives a significant effect on the survival and growth of seedlings after reforestation (Bayala et al. 2009). In this experiment, the dry weight of seedlings parts for each shading and fertilization treatment was investigated in order to determine the healthiness of the seedlings and the results are presented in Figure 2(a). The highest root dry weight value of 2.73 ± 0.32g was measured for the 1.0 g/L fertilization treatment in the full sunlight condition while the lowest value of 0.50 ± 0.10g was measured for the 3.0 g/L fertilization treatment in the 75% shading treatment condition (Figure 2(a)). No significant differences in root dry weight were found in the 35% shading treatment condition between the different fertilization concentrations treatments, while in the case of the 55% and 75% shading treatments, the root dry weight value of the seedlings was highest in the no fertilization treatment (Figure 2(a)). In the full sunlight treatment condition, the no fertilization treatment showed a higher value of root dry weight than the 2.0 g/L and 3.0 g/L fertilization treatments, and this resulted from the promotion of root development for securing nutrients at wider and deeper soil depths. Therefore, the interaction effect of the fertilization treatments was unequal and highest at the full sunlight treatment condition for root growth response in terms of dry mass production and decreased appreciably with increases in shading condition (Figure 2(a)).

The 1.0 g/L fertilization treatment type in the full sunlight treatment condition showed the highest value of shoot dry weight. The 0.5 g/L, 1.0 g/L and 1.5 g/L fertilization treatments in the full sunlight treatment condition showed the highest value of the dry weight of leaves. The dry weight of shoot and leaves in the different fertilization treatments showed no significant differences in the 75% shading condition, indicating that differences in the shoot and leave dry mass production was smaller at higher fertilization and shading treatment conditions (Figure 2(b,c)). For the total dry weight of seedlings, the 1.0 g/L fertilization treatment in the full sunlight treatment condition showed the highest value of 16.93 ± 0.85g while the 75% shading treatment with no fertilization showed the lowest value (Figure 2(d)). Since the no fertilization treatment in all shading treatments showed the lowest value in seedlings' growth response characteristics, it is evident that

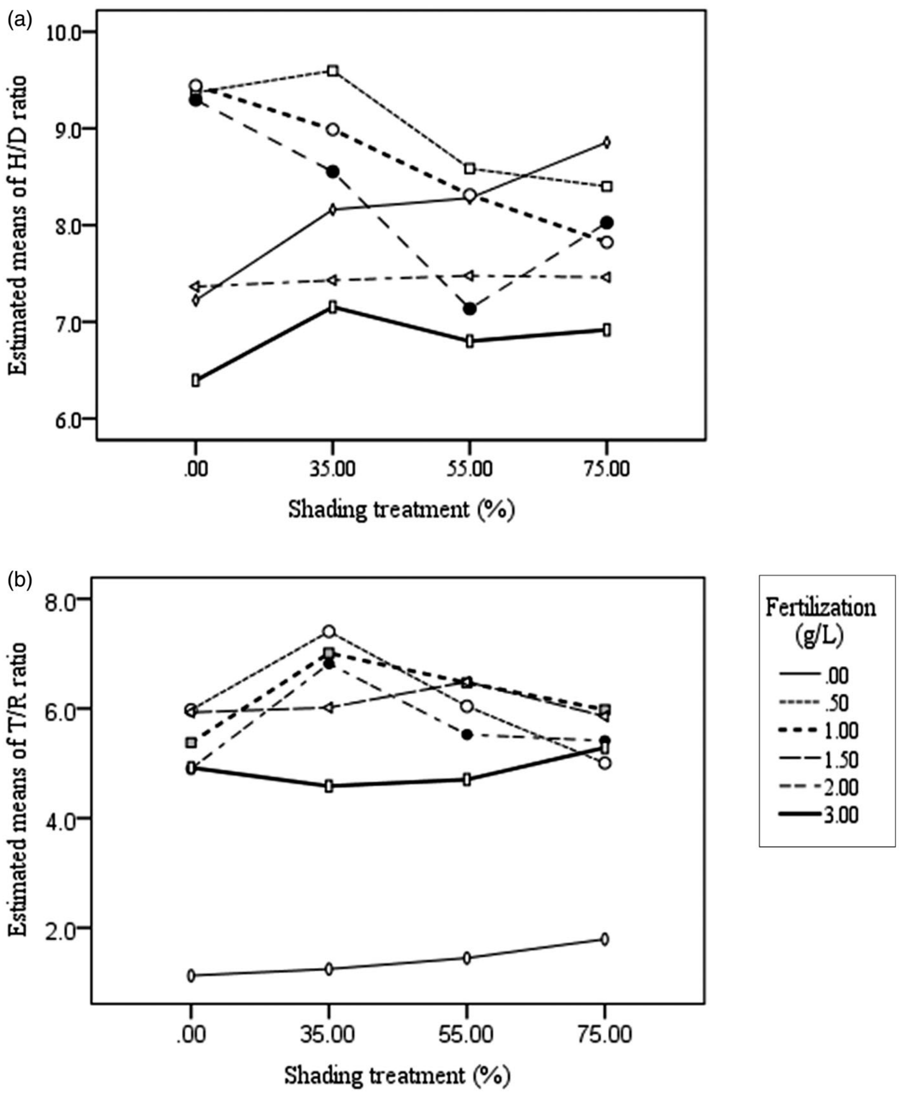

Figure 3. Effects of shading rates and fertilization concentrations on H/D ratio (a) and T/R ratio (b) of *Chamaecyparis obtusa* container seedlings. Data are estimated marginal means in a two-way ANOVA at a significant level of $p < 0.05$.

growth increase in seedlings' height and root collar diameter, for example, was due to the effect of medium (0.5–1.5g/L) fertilization treatment. This is because seedling growth decreased with increased fertilization concentrations (2.0 g/L and 3.0 g/L) beyond an optimum level of 1.0 g/L (Figure 2). Fertilization treatments exceeding an appropriate fertilization level causes growth inhibition in seedlings (Binkley et al. 1995; Kwon et al. 2009). In this study, the total dry weight of seedling parts decreased with increases in the shading rate. This might be the result of differences in the photosynthetic products because of reduced light intensity for the different shading treatment, as low relative light intensity reduce the dry weight of seedlings (Strothmann 1967). Therefore, the interaction effect of the fertilization treatments was unequal and highest at the full sunlight treatment condition for the shoot, leaves and total growth response, in terms of their dry mass production, and the differences narrowed significantly with increases in the shading condition, due to differences in seedling growth response following fertilization treatments (Figure 2(a–d)). The results are consistent with the study hypothesis that the effect of the fertilization treatments on seedlings' growth characteristics was in general mostly unequal across all the shading or sunlight treatment conditions, except for the 75% shading treatment condition where notably only small differences in the seedling growth characteristics were observed.

H/D ratio and T/R ratio

The ratio of seedling height to root collar diameter (H/D ratio) is the value of seedling height divided by root collar diameter and this index evaluates whether the seedling is thick and strong or thin and weak according to the H/D ratio. It indicates the ability of seedlings to bear physical damage such as wind or dehydration and it is widely used as the index to evaluate a thin and weak seedling with a high H/D ratio, which has grown under high growth density and low light intensity (Thompson 1985; Haase 2007b). In this experiment, the changes in H/D ratio and T/R ratios according to shading and fertilization treatments are shown in Figure 3(a,b), respectively.

Seedlings from the 0.5 g/L fertilization treatment with 35% shading had the highest H/D ratio of 9.60 ± 0.24, whereas the lowest H/D ratio of 6.39 ± 0.74 was observed from seedlings in the 3.0 g/L fertilization treatment in the full sunlight treatment condition (Figure 3(a)). The 0.5 g/L, 1.0 g/L and 1.5 g/L fertilization treatments in the full sunlight treatment condition showed similar H/D ratio values of 9.37 ± 0.39, 9.44 ± 0.39 and 9.29 ± 0.58, respectively, and the H/D ratio decreased as the fertilization concentration increased (Figure 3(a)). The 35% shading treatment showed no significant differences according to the fertilization treatments, while the 75% shading treatment with no fertilization treatment showed the highest H/D ratio (Figure 3(a)). The seedlings from the 3.0 g/L fertilization treatment showed the lowest H/D ratio, and the overall results indicated that the H/D ratio decreased as the fertilization concentration increased (Figure 3(a)). This present result is inconsistent with that of Park et al. (2010a), who is a related experimental study using *Fraxinus rhynchophylla*, *Fraxinus mandshurica*, *Pinus koraiensis* and *Abies holopylla* tree species found no significant differences in the H/D ratio between different fertilization treatments. The discrepancy in the results could be related to differences between the study tree species because there are differences in the appropriate H/D ratio between the bare root seedling and the container seedling according to tree species (Johnson et al. 1996). According to Johnson et al. (1996), except for *Pinus densiflora*, H/D ratios in the range from 9.0 and 10.0 is appropriate for container seedlings and H/D ratios below 7.0 are appropriate for bare-root seedlings of needle-leaf trees. For this present experiment, it is considered that the container seedlings with the appropriate H/D ratio are those from the full sunlight treatment condition with 0.5 g/L, 1.0 g/L and 1.5 g/L fertilization concentrations, and those from the 35% shading treatment with 0.5 g/L fertilization concentration (Figure 3(a)).

The T/R ratio is the value that indicates the balance between the growths of above- and below-ground parts of seedlings. The T/R ratio is used as the seedling quality evaluation index. In the case of normal seedling growth, a lower T/R ratio value indicates healthier seedling (Haase 2007a) and a possible higher seedling survival rate (Lopushinsky and Beebe 1976). In this experimental study, the fertilization treatments showed a higher T/R ratio than the no fertilization control treatment (Figure 3(b)). The 35% shading treatment with 0.5 g/L fertilization concentration showed the highest value of 7.40 ± 0.50 and the no fertilization treatment in the full sunlight treatment condition showed the lowest value of 1.13 ± 0.7 (Figure 3(b)). One plausible explanation is that the growth of the seedling above-ground parts was promoted due to the fertilization treatment and the effects of part (35%) shading protection from the scouring sun that might have helped keep seedling from turning brown and crispy around the edges. Consistent with the above results, additions of nutrients promote photosynthesis in planted seedlings and cause active growth of the above-ground parts (Wallenda et al. 1996; Malik and Timmer 1998). In general, the interaction effect of the fertilization treatments on the seedling H/D and T/R was mostly significantly different across the shading treatment conditions (Figure 3(a,b)), suggesting that the seedling growth depends on the fertilization and shading treatment conditions.

Meanwhile, the no fertilization treatment of each shading treatment showed the tendency of an increased T/R ratio with an increased shading rate (Figure 3(b)). Consistent with this study result, (Choi et al. 2002) found the T/R ratio of *Betula platyphylla* var. *japonica*, *Betula schmidtii* and *Zelkova serrata* seedlings to increase with decreases in the light intensity. Young seedlings in insufficient light environments use most of the photosynthetic products to increment their height growth in order to hold favorable positions in the light receiving competition so that the T/R ratio increases (Kimmins 1997).

3.4. Seedling quality indices

Plants distribute substances obtained as a result of the photosynthetic process to each part and the distribution ratio of substances for each part is usually expressed by leave dry weight ratio (LWR), shoot dry weight ratio (SWR) and root dry weight ratio (RWR) (Hilbert 1990). According to Quoreshi and Timmer (2000), the appropriate distribution of substances to each part of a seedling indicates a healthy condition of seedlings. In this study, the effects of shading rate and fertilization treatments on the distribution of substances to each part of the *Chamaecyparis obtusa* container seedlings were also investigated and the results are presented in Figure 4. The LWR represents the ratio of the dry weight of leaves to the total dry weight of seedling, the SWR represents the dry weight ratio of stem and the RWR represents the ratio of dry root weight to the total dry weight of seedlings.

The LWR of the 1.5 g/L fertilization treatment with 55% shading showed the highest value of 0.60 ± 0.01 and the no fertilization treatment in the full sunlight treatment condition showed the lowest value of 0.34 ± 0.02 (Figure 4(a)). In each shading treatment, the LWR of all fertilization treatments ranged from 0.51 and 0.60 and showed no significant differences between the fertilization concentration treatments (Figure 4(a)). However, there was a relatively significant difference in the LWR between the no fertilization control treatment and the fertilization treatments (Figure 4(a)).

The SWR of the 35% shading treatment with 0.5 g/L and 2.0 g/L fertilizer additions and the 75% shading treatment with 2.0 g/L fertilizer additions showed the highest value of 0.33 ± 0.02, 0.33 ± 0.02 and 0.33 ± 0.01, respectively, while the no fertilization control treatment in the full sunlight treatment condition showed the lowest value of 0.19 ± 0.01 (Figure 4(b)). There was a significant difference in the SWR between the no fertilization treatment and the 0.5 g/L, 1.0 g/L, 1.5 g/L 2.0 g/L and 3.0 g/L fertilization treatments in the full

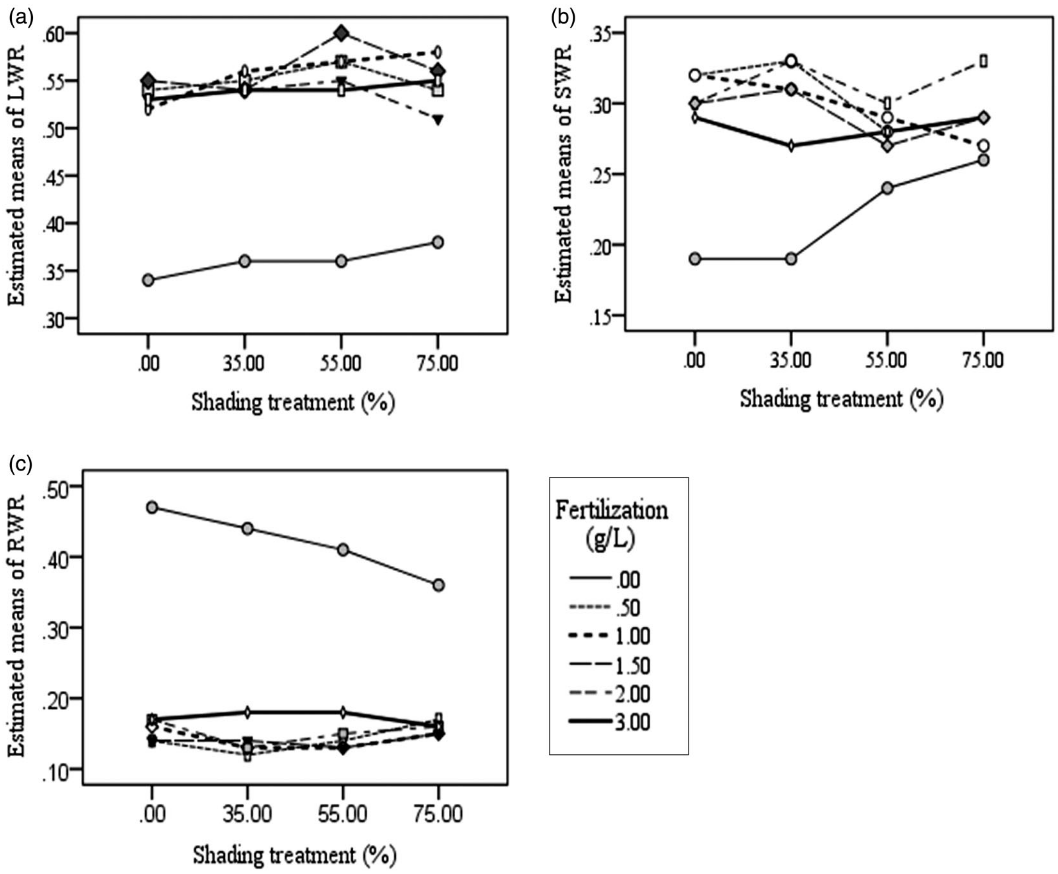

Figure 4. Effects of shading rates and fertilization concentrations on LWR (a), SWR (b) and RWR (c) of *Chamaecyparis obtusa* container seedlings. Data are estimated marginal means in a two-way ANOVA at a significant level of $p < 0.05$.

sunlight and 35% shading treatment conditions, but there was no significant difference in the SWR between the different fertilization concentration treatments (Figure 4(b)). The 55% and 75% shading treatments showed no statistically significant differences between the different fertilization concentration treatments (Figure 4(b)).

In this experimental study, the fertilization treatments showed higher LWR and SWR than the no fertilization control treatment, and generally, there were no significant differences between the different fertilization concentration treatments in the LWR and SWR (Figure 4(a,b)). This result is consistent with that of a previous study by Yoon (2013), which found that fertilization treatments of *Acer mono* Max. showed higher LWR and SWR than the no fertilization treatment while there was no significant difference in the LWR and SWR between the fertilization treatments. In contrast, the LWR of seedlings is higher when the shading rate becomes stronger (Walters et al. 1993; Cornelissen et al. 1996). This difference in results might be due to differences in growth response to shading treatment between tree species.

The RWR of the no fertilization treatment in the full sunlight treatment condition showed the highest value of 0.47 ± 0.01 and the 35% shading treatment with 0.5 g/L showed the lowest value of 0.12 ± 0.01 (Figure 4(c)). In particular, the no fertilization treatment showed a significantly higher RWR than the fertilization treatments independently of the shading rate, and there was no significant difference in the RWR between the different fertilization concentration treatments (Figure 4(c)). Similarly, Reynolds and Antonio (1996) found that seedling RWR value decreased when nitrogen fertilization was applied to the seedlings. In addition, Sung et al. (2011) also found that *Chinese Evergreen Oak* container seedlings treated with shading and fertilization treatments showed a lower RWR value than the no fertilization control treatment. This is probably because the seedlings promoted their root development relatively stronger in order to get out of nutrient deficiency conditions. In general, except for the no fertilization control treatment, the magnitude of the difference of the fertilization treatment effect on the LWR, SWR and RWR of the seedlings was appreciably comparable across all the shading treatment conditions, suggesting that there was an only insignificant interaction effect of the fertilization and shading treatments on these variables.

Seedling quality index (SQI) is calculated using the dry weight, H/D ratio and T/R ratio of seedlings as factors and a higher SQI value indicates a healthier seedling (Thompson 1985; Bayala et al. 2009). In this study, the 1.0 g/L fertilization treatment showed the highest SQI value of 1.20 ± 0.04 while the 75% shading treatment with 3.0 g/L fertilization treatment showed the lowest SQI value of 0.26 ± 0.05 (Figure 5). For each shading treatment, the 0.5 g/L, 1.0 g/L and 1.5 g/L fertilization treatments showed higher SQI values while the 2.0 g/L and 3.0/L fertilization treatments showed

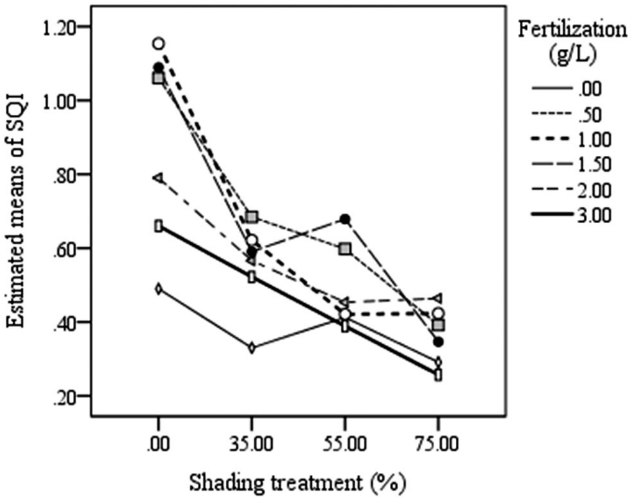

Figure 5. Effects of shading rate and fertilization concentration treatments on seedling quality index (SQI) of *Chamaecyparis obtusa* container seedlings. Data are estimated marginal means in a two-way ANOVA at a significant level of $p < 0.05$.

lower SQI values (Figure 5), as a consequence of excessive fertilization that might have hampered the growth of the seedlings. In addition, the SQI was highest when the light intensity was strongest as in the full sunlight treatment condition (Figure 5). The full sunlight and the 35% shading treatments showed significant differences in the SQI values among the different fertilization treatments, but as the shading rate increased, the fertilization effect decreased, and no statistical significance in the SQI values was observed at the 75% shading treatment (Figure 5). The observed significant differences in the SQI indicated an appreciable interaction effect of the fertilization and shading treatments, particularly in full sunlight conditions. This suggests that the SQI depended on the level of fertilization concentration and shading conditions. In general, the results indicate that the fertilization effect on seedling SQI was appreciably unequal across the shading conditions, and suggested that optimal SQI can be achieved at lower fertilization concentrations (0.5–1.5g/L) and lower shading conditions (0.0-35%). This result is similar to that of Park et al. (2010a), who found that *Fraxinus mandshurica* and *Fraxinus rhynchophylla* seedlings treated with nitrogen fertilizer showed higher SQI values, and *Pinus koraiensis* container seedlings treated with 1.0 g/L fertilization showed the highest SQI values (Kim et al. 2015).

4. Conclusion

Chamaecyparis obtusa is the main reforestation species in the southern part of South Korea and its reforestation area cover is increasingly being expanded. This study was undertaken with the purpose of providing preliminary data for producing excellent quality *Chamaecyparis obtusa* container seedlings with the aim of investigating the response of seedlings' growth characteristics to varying artificial shading and fertilization treatments. The effects of the fertilization treatments varied according to the shading rate, and this is the result of the interaction effect of sunlight conditions and fertilization concentrations on the growth of *Chamaecyparis obtusa* container seedlings. The magnitude of the differences in the interaction effect of the fertilization treatments is higher in lower than in higher shading treatment conditions. Generally, sun shading of seedlings is undertaken to prevent seedling damage from high temperature and scouring sun. Because *Chamaecyparis obtusa* seedlings in this experiment showed the highest growth in full sunlight conditions, it is proper to apply low sunlight shading of below 35% during seedlings cultivation. Also, in the case of fertilization treatment, as the fertilization concentration increased beyond 2.0 g/L and 3.0 g/L, the effect on seedling growth promotion decreased and the growth inhibition of seedlings and damage to the shape of leaves occurred due to excessive fertilization even though a large number of nutrients were supplied. Therefore, 1.0 g/L fertilization concentration is the most appropriate fertilization treatment amount to enhance the growth of 2-year-old *Chamaecyparis obtusa* container seedlings. On the other hand, it should be considered that different results may be obtained by using seedlings under the other growth environments and conditions. The results of this study show the importance of ensuring appropriate light intensity and fertilization amount in the cultivation of seedlings in controlled greenhouse conditions. Therefore, the results provide useful preliminary data for producing excellent *Chamaecyparis obtusa* container seedlings, which are currently of growing interest and demand for reforestation and area cover expansion in the southern part of Korea, owing to its resilience to climate change impacts and importance in the forest recreation culture.

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