Turkish Journal of Agriculture and Forestry

Volume 45 | Number 3 Article 1

1-1-2021

Growth and nutrient responses of Betula platyphylla, Larix kaempferi, and Chamaecyparis obtusa to different application methods of solid compound fertilizer

JEONG MIN SEO

HUONG THI THUY DAO

BYUNG BAE PARK

Recommended Citation

SEO, JEONG MIN; DAO, HUONG THI THUY; and PARK, BYUNG BAE (2021) "Growth and nutrient responses of Betula platyphylla, Larix kaempferi, and Chamaecyparis obtusa to different application methods of solid compound fertilizer," *Turkish Journal of Agriculture and Forestry*: Vol. 45: No. 3, Article 1.
https://doi.org/10.3906/tar-2005-80
Available at: https://journals.tubitak.gov.tr/agriculture/vol45/iss3/1

Turkish Journal of Agriculture and Forestry
http://journals.tubitak.gov.tr/agriculture/
Research Article

Turk J Agric For
(2021) 45: 253-265
© TÜBİTAK
doi:10.3906/tar-2005-80

Growth and nutrient responses of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa* to different application methods of solid compound fertilizer

Jeong Min SEO[1,2], **Huong Thi Thuy DAO**[1], **Byung Bae PARK**[1,*]
[1]Department of Environment and Forest Resources, Chungnam National University, Daejeon, Republic of Korea
[2]Garden Plan Material Development Team, Sejong National Arboretum, Sejong-si, Republic of Korea

Received: 20.05.2020 • **Accepted/Published Online:** 31.01.2021 • **Final Version:** 23.06.2021

Abstract: We investigated the effects of different placement methods of applying slow-release fertilizer on the growth and foliar nutrients of three contrasting tree species (i.e., fast-growing *Betula platyphylla* and *Larix kaempferi* and slow-growing *Chamaecyparis obtusa*) to provide implications for increasing their growth and survival in marginal forest lands. We applied 84 g pot^{-1} of solid compound fertilizer (SCF) at different positions: no fertilization (CON), subsurface placement (SCF$_s$), and bottom placement [35-cm depth (SCF$_b$)] in a greenhouse condition. Results revealed that the height and RCD (root collar diameter) of the three species had the highest growth under SCF$_s$. Total biomass across SCF$_s$, SCF$_b$, and CON ordered as follows 130, 72, and 28 g seedling^{-1} in *B. platyphylla*, 89, 38, and 27 g seedling^{-1} in *L. kaempferi*, and 61, 24, and 23 g seedling^{-1} in *C. obtusa*. In contrast, SCF$_b$ resulted in the highest root length across the treatments in all species. The root biomass allocation was also higher in SCF$_b$ (28%–40%) than that of SCF$_s$ (12%–24%). SCF$_s$ had higher N uptake in all species than the other treatments. In conclusion, SCF$_s$ has shown to be the most effective placement method of SCF application for increasing aboveground biomass and nutrient (N) acquisition, while SCF$_b$ was the placement effective for increasing root length and root biomass growth in all species. These results are relevant to the promotion of ecofriendly and cost-effective fertilization approach of increasing growth and survival of economically important forest tree species, especially in steep slope and erosion-prone areas or marginal forest lands.

Key words: fast-growing species, seedling growth, slow-release fertilizer, vector analysis

1. Introduction

Fertilization plays a crucial role in increasing nutrient availability and plant productivity (Ryan, 2008; Ünlükara, 2019; Aung et al., 2020). However, the improper use of chemical fertilizer can put our natural environments at high risk due to leaching and surface runoff, especially in high-rainfall areas (Castillo, 2010; Stipešević et al., 2019; Nadkarni and Wheelwright, 2000). Fertilizer management practices, such as the optimization of application placement methods, have been proposed in many developed and developing countries (Baker and Richards, 2002; Kronvang et al., 2005: Zheng et al., 2017) as a response to unsustainable fertilization. Innovative strategies including the use of slow-release fertilizers (SRF), which release nutrients into the environment in a slow or controlled manner, have also been developed (Ramli, 2019).

Application of SRFs such as solid compound fertilizer (SCF) reduces nutrient losses due to leaching and is, therefore, an environment-friendly and economical approach (Zareabyaneh and Bayatvarkeshi, 2015). For example, Zareabyaneh and Bayatvarkeshi (2015) have already shown that the use of SRFs can help mitigate nitrate loss by up to 36% (Zareabyaneh and Bayatvarkeshi 2015). However, while much is known about the proper methods of applying SRFs in many agricultural plants (e.g., ; Rahman and Zhang, 2018; Ebrahimi et al., 2019; Nielsen et al., 2019), such information is limited for economically important forest tree species.

Appropriate fertilizer placement has been attributed to improved root growth and nutrient uptake, and reduced environmental pollution (Shen et al., 2013). Plant growth can be considerably enhanced, especially during the early growing stage, when the fertilizer is applied in defined soil areas close to roots (Bittman et al., 2012). For example, studies revealed that the surface banding of fertilizer at c.a. 2–3 cm depth, which refers to a placement of fertilizer in a narrow strip running parallel to the crop row, produced the highest growth compared to below root placement and broadcast method (Alam et al., 2018). Furthermore, it was reported that the broadcasting method of fertilizer

---

[*] Correspondence: bbpark@cnu.ac.kr

application (fertilizers are spread across the soil surface) was very prone to inefficient fertilization, which increased greenhouse gas emission by 60%[1]. In the agriculture sector, majority of the applied fertilizer using the broadcast method was lost to the environment (IFDC, 2013) due to rain, irrigation, or sublimation by sun radiation (Bakhtiari et al., 2014).

Here we investigated the effects of different placements of fertilizer application on the growth and foliar nutrients of three contrasting species [i.e., broadleaf and deciduous fast-growing species *Betula platyphylla* Suk., needle-leaf and deciduous fast-growing *Larix kaempferi* (Lamb.) Carrière, and scale-like leaf and evergreen slow-growing *Chamaecyparis obtusa* (Siebold & Succ.) Endl.] to provide implications for increasing growth and survivability in marginal forest lands. These species are economically and ecologically important in a variety of ways, which have been widely planted in temperate forest plantations particularly in East Asia. Plants of different potential growth rates respond differently to fertilizer (Hafsi et al., 2011). For example, slowly growing spruce species have lower plasticity in biomass allocation than fast-growing conifers (Miller and Hawkins, 2007), and fast-growing *Pinus radiata* D. Don prefers to allocate more to the aboveground biomass under N and P fertilization (Bown et al., 2009). However, while much is known about the responses fast-growing and slow-growing species to inorganic fertilizers, their responses on different placement methods of applying slow or controlled release fertilizer have not yet been investigated. Thus, we hypothesized that the increase in growth and nutrient uptake is more evident in the surface placement of SCF than the bottom placement method in all species.

2. Materials and methods

2.1. Experimental area

This experiment was carried out in the greenhouse condition at Chungnam National University (36° 22' 12" N, 127° 21' 17" E) in Yuseong-gu, Daejeon, Republic of Korea from April 2018 (planting period) to October 2018 (harvesting period). The temperature and relative humidity were measured at 12 pm and 6 pm daily in the greenhouse, giving us an average temperature of 28.7 °C and relative humidity of 52.7% (Figure 1).

2.2. Experimental materials

The experimental seedlings in the study were selected based on potential growth rate characteristics (Table 1). *Betula platyphylla* Suk. is native to Korea and Japan, which is a fast-growing pioneer species widely distributed in low-elevation regions and is usually a dominant species in many temperate forest ecosystems even under normal to poor soil conditions (Sato, 1986). Second, *Larix kaempferi* (Lamb.) Carrière is a fast-growing deciduous coniferous species with geographic and genetic origin in Japan (Cáceres et al., 2018). The slow-growing species was *Chamaecyparis obtusa* (Siebold & Succ.) Endl. which is an evergreen coniferous species native also to Japan. The species can grow in soil characterized by low pH and low contents of exchangeable Ca (Sawata and Kato, 1991).

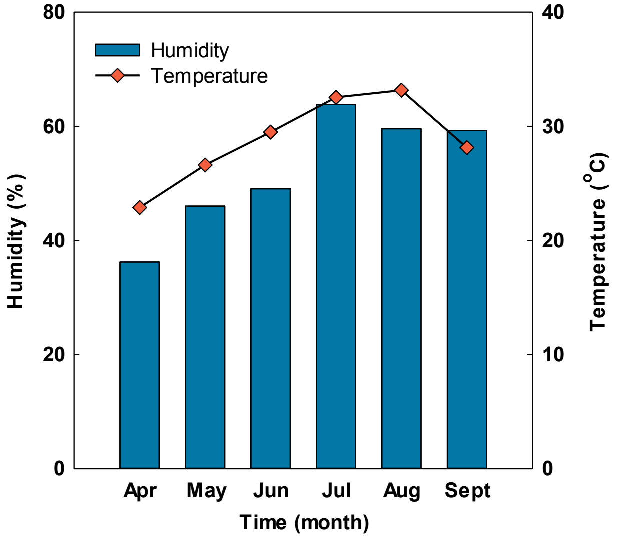

Figure 1. Monthly mean temperature and humidity in the greenhouse during the experiment (April–September 2018). Air temperature and humidity in September were measured until September 7, 2018.

The pot used had a total volume of 35 L, depth of 46 cm, and an inner surface diameter of 36 cm. Each pot received four pieces (c.a. 84 g) of solid compound fertilizer (SCF, KG Chemical, Ulsansi, Gyeongsangnam-do) with 10.08 g pot^{-1} nitrogen (N), 2.10 g pot^{-1} phosphorous (P) and 3.36 g pot^{-1} potassium (K), which is a slow-release inorganic granulated fertilizer.

The soil used in this study was sandy loam soil (74.70% sand, 16. 70% silt, and 8.60% clay) with a pH and organic matter content of 5.24 and 0.76%, respectively. Moreover, the soil had the following characteristics: total N = 0.10 g kg^{-1}, available P = 10.69 mg kg^{-1}, exchangeable K^{+}, Ca^{+}, and Mg^{+}= 0.18, 1.79, and 1.78 cmol$_c$ kg^{-1}, respectively, and cation exchange capacity (CEC) = 3.79 cmol$_c$ kg^{-1}.

2.3. Experimental design

Three fertilization placement methods for each species were randomized as follows: no fertilization as control (CON), applying four SCF granules at the subsurface (2–3 cm depth, SCF$_s$) and covered by soil, and treating four

---

[1] International Fertilizer Development Centre (IFDC) (2013). Fertilizer Deep Placement (FDP); IFDC: Muscle Shoals, AL, USA. Website https://ifdc.org/fertilizer-deep-placement/ [accessed on 08 May 2020].

Table 1. Botanical and ecological description of the three tree species used in this study.

	Betula platyphylla	*Larix kaempferi*	*Chamaecyparis obtusa*
Common name	Japanese white birch	Japanese larch	Hinoki cypress
Growth rate	Fast-growing	Fast-growing	Slow-growing
Mature tree height (m)	15–20	20–30	20–35
Mature DBH (cm)	> 60	~100	~ 100
Leaf functional type	Deciduous	Deciduous	Evergreen
Mycorrhizae	Ectomycorrhizae	Ectomycorrhizae	Arbuscular

SCF granules at a 35-cm depth from the surface of the pot (SCF_b), with nine replications each. Pots were then arranged in three lines at the center of the greenhouse following a 1-m distance between the lines and a 0.8-m distance between the pots of each line. A total of 81 seedlings (3 treatments × 9 replicates/treatment × 3 species) were used in the study. In this experiment, we used each pot as an observational unit as well as an experimental unit.

We used one-year-old containerized seedlings of *B. platyphylla*, *L. kaempferi*, and *C. obtusa* with 54.7 ± 1.4, 38.7 ± 0.4 and 38.3 ± 0.5 cm in height and 5.4 ± 0.1, 4.8 ± 0.1, and 4.0 ± 0.1 mm in root collar diameter (RCD), respectively. The roots of each seedling were cut to make their length uniform (c.a. 10 cm) before planting. The fertilizer under SCF_b treatment was applied first before planting the seedlings.

Shading of approximately 35% using knitted shade cloth was set up in the greenhouse to protect the seedlings from high temperature. Weeds growing in each pot were removed manually (four times during the experiment period). We also checked the presence of insects on each seedling throughout the experiment period, and a chemical insecticide with a mixing ratio of 2.5 or 5 g with 5 L of water was sprayed on the seedlings once a month.

2.4. Growth measurements

Seedling height and RCD of each species were measured biweekly starting 2 weeks after planting to determine the period in which the lowest and highest growth occurred.

At each measurement time until the end of the experiment, relative height and relative RCD growth (%) of each species were calculated based on the height and RCD values relative to those at initial planting, respectively. The use of relative values allows better comparison of parameters measured among species and individuals that differ in growth characteristics (i.e., fast- and slow-growing species).

At harvesting time, we counted first the number branches (i.e., all main and lateral branches attached on the stem) before harvesting the aboveground parts, which was done by dividing the total number of branches per seedling by the plant height for all species. After carefully washing the roots, the total length of the taproot was measured from RCD to the longest root tip before harvesting the belowground parts. Roots with < 2 mm diameter were classified as fine root (FR) and coarse root (CR) for those with ≥ 2 mm root diameter. Thereafter, we harvested the seedlings and separated them into different plant components (i.e., root, stem, branch, and leaf). All plant samples (by component) were then oven-dried at 70 °C for 72 h to a constant weight. The total biomass production and the proportion of biomass by plant component were measured following the procedures in Sestak et al. (1971). Due to the differences in leaf morphology, the number of branches and branch biomass were not measured for *C. obtusa*.

2.5. Foliar nutrient and soil analysis

To analyze the nutrient uptake (N, P, and K) at the end of the experiment, we collected ten fully mature and healthy broadleaves of *B. platyphylla,* all needle leaves of seedlings of *L. kaempferi,* and all scale-like leaves (including modified green twigs) of *C. obtusa* from the third and/or fourth foliage around the seedling. Leaf samples were oven-dried at 70 °C for 48 h, weighed, and then ground using a Wiley mill to pass through a 1-mm screen mesh. To digest the organic matter, a block digester (BD-46, Lachat Instruments, USA) with a combination of H_2SO_4 and $HClO_4$ was used. An automated ion analyzer (Quik Chem AE, Lachat Instruments, USA) was used to determine the total N and P levels in the leaf samples. Lastly, the K was determined using an atomic absorption spectrometer (AA280FS, Varian, USA).

The physical and chemical properties of the soil samples (n = 3) used in the study were analyzed before the fertilization treatment. The following methods were used for the soil analysis: pH by the pH-meter (1:5 soil-water) method, organic matter (OM) and total nitrogen (TN) by the dry oxidation (utilizing C-N analyzer equipment) method, and available phosphorus (P) with the Lancaster method. The other soil properties such as cation exchange capacity (CEC), electrical conductivity, and exchangeable K^+, Ca^{2+}, and Mg^{2+} were analyzed using the 1N-ammonium acetate replacement leaching method, EC-meter (1:5 soil-water) method, and 1N-ammonium acetate leaching with the atomic absorption spectrophotometry method, respectively.

2.6. Vector analysis

Vector analysis was used to simultaneously compare plant growth, nutrient concentration, and nutrient content in response to nutrient addition by the fertilization treatments in an integrated graphics format, following the procedures and interpretations presented in Haase and Rose (1995) (Figure 2). A vector diagram was constructed by which nutrient content (x-axis) was plotted against nutrient concentration (y-axis). Because nutrient content was a function of concentration and weight, the plotted data represented foliar weight as the *z*-axis.

2.7. Statistical analysis

All the statistical analyses were run in R Statistical Package Software (version R-3.5.1) at $\alpha = 0.05$ and all data passed the test for the normality and equality of variance or were transformed properly before statistical analyses. One-way analysis of variance (ANOVA) followed by Duncan's multiple comparison tests was conducted to determine the effects of SCF treatments on height and RCD growth, biomass growth, number of branches, root length, and nutrient concentrations. To analyze the treatment effects on height and RCD growths across time, repeated measures analysis of variance (RM ANOVA) was also employed. Linear regression analysis was used to investigate the growth tendency of height and RCD in each SCF placement treatment for all species.

3. Results

3.1. Height and root collar diameter growth

Significant time and treatment effects on the height and RCD growth was detected in three species (Table 2, Figure 3 and Figure 4). The effect of SCF_s treatment on the height and RCD growths was generally faster to occur than that in SCF_b and control for all species (Table 3, Figure 3 and Figure 4). The fastest growth occurred between 42nd and 56th day periods for both parameters in three species, but the amount of growth was significantly different among the treatments. *B. platyphylla* grew the fastest at SCF_s with 94% in height and 80% in RCD, but at SCF_b with 25% in both parameters, and at CON with 36% in height and 15% in RCD. *L. kaempferi* also grew the fastest in SCF_s with 65% in height and 102% in RCD, but with only 18% in height and 35% in RCD at SCF_b, and only 12% in height and 25% in RCD at CON. Although the huge increase in the growth parameters of *C. obtusa* was also recorded in the same periods, this increase was the lowest among the three species with 44% in height and 35% in RCD at SCF_s and with 19% in both parameters at SCF_b and CON.

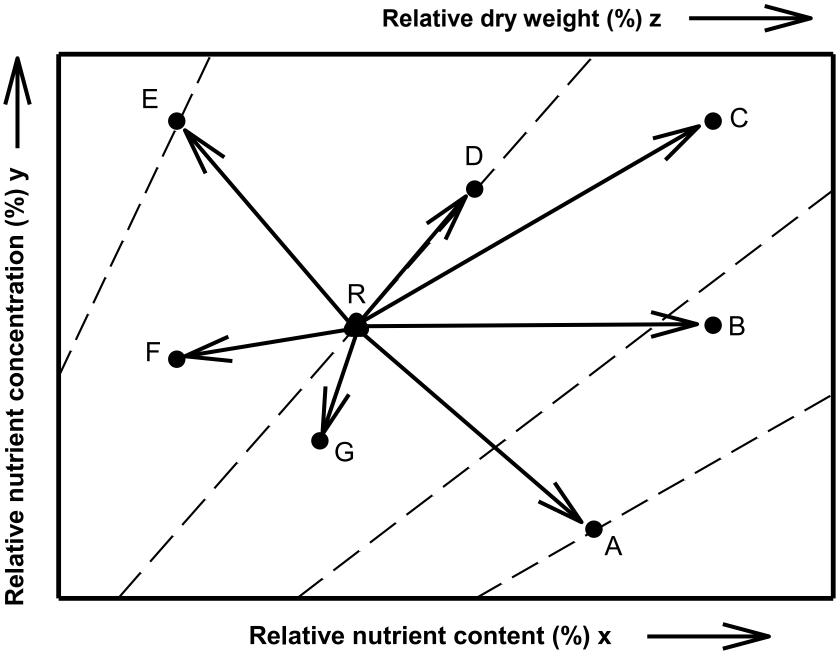

Figure 2. Schematic relationships among nutrient concentration, nutrient content, and foliar dry weight of an element at different treatments. Reference point (R) is normalized to 100% representation of control. Vector shifts (A–G) indicate increase (+), decrease (–), or no change (0) in relative dry weight and nutrient status to the reference point (adapted from Timmer and Stone 1978).

Table 2. The p-values derived from one-way ANOVA for growth parameters and foliar nitrogen (N), phosphorus (P) and potassium (K) concentrations of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa* subjected to different SCF placements treatments.

	Betula platyphylla	***Larix kaempferi***	***Chamaecyparis obtusa***
Growth parameters			
Height	< 0.001	< 0.001	< 0.001
RCD	< 0.001	0.002	< 0.001
CoH	< 0.001	< 0.001	< 0.001
CoD	< 0.001	< 0.001	< 0.001
CR	< 0.001	0.014	< 0.001
FR	0.001	0.719	0.714
Root length	0.025	0.070	0.036
Root biomass	< 0.001	0.314	0.012
Leaf biomass	< 0.001	< 0.001	< 0.001
Branch biomass	< 0.001	< 0.001	< 0.001
Stem biomass	< 0.001	< 0.001	< 0.001
Total biomass	< 0.001	< 0.001	< 0.001
Foliar nutrient concentrations			
N	0.001	< 0.001	< 0.001
P	0.070	0.220	0.570
K	0.420	0.770	0.710

CoH and CoD are coefficients in the linear regression equation of relative seedlings height and root collar diameter growth, respectively; CR: coarse root biomass, FR: fine root biomass. Significant p-values are written in bold.

At the end of the experiment period, the height and RCD of all the studied species also showed the highest growth under SCF_s for all species (Figure 3 and Figure 4). For example, the height under SCF_s was higher than that of SCF_b and CON by 112% in *B. platyphylla*, 79% in *L. kaempferi*, and 29% in *C. obtusa*.

3.2. Biomass growth and allocation

The effect of the SCF placement treatments on total biomass growth and allocation between aboveground and belowground of the three species were significantly different ($p < 0.001$) across the treatments (Figure 5). The highest total biomass growth was observed at SCF_s (130.3 g seedling^{-1} for *B. platyphylla,* 89.2 g seedling^{-1} for *L. kaempferi*, and 60.5 g seedling^{-1} for *C. obtusa*), while the lowest growth was observed at CON for all species (22.8 g seedling^{-1} to 27.7 g seedling^{-1}). There was no significant difference detected between SCF_b and control in all species, except for *B. platyphylla*.

Generally, the leaf biomass proportion increased as the root biomass proportion decreased in all species and treatments (Figure 5). The root biomass allocation was higher in SCF_b (28%–40%) than that of SCF_s (12%–24% of total biomass). CON and SCF_b had a very similar pattern of biomass allocation to leaf and root in all species.

The root length of the three species varied significantly ($p < 0.05$) across the fertilizer placement treatments (Figure 6). Generally, root length of all species grown in SCF_b was significantly higher than those at CON (except for *C. obtusa*, Figure 6c) and SCF_s. The SCF_s produced a significantly higher number of branches compared to control and SCF_b for *L. kaempferi* and *B. platyphylla* (Figure 6).

3.3. Foliar N, P, and K response

The foliar NPK responses to fertilizer placement treatment showed similar pattern by element in all species, but a significant difference was detected only in N concentration across the treatments for *B. platyphylla* and *L. kaempferi* (Table 4). SCF_s resulted in a significantly higher foliar N content than SCF_b and CON in all species.

Vector analysis showed different responses of foliar nutrients on fertilization placement treatments in each species (Figure 7). The general pattern is that the SCF_s was a more responsive treatment to change in N compared to the control than the SCF_b. In *B. platyphylla*, the foliar dry

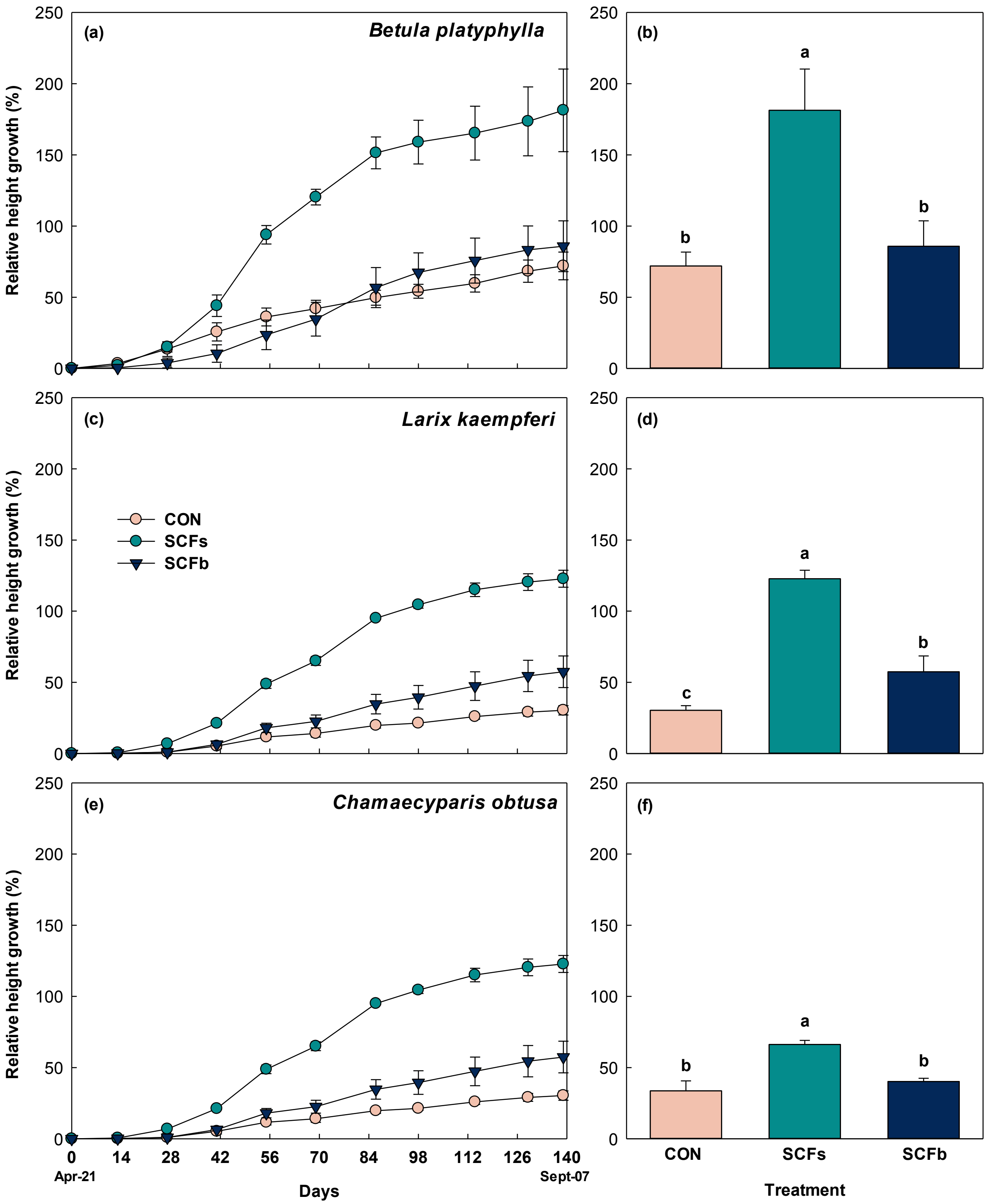

Figure 3. Relative seedling height growth trends (a, c, e) of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa*, and the significant differences in relative height growth across the treatments at the end of the experiment (b, d, f). CON, SCF_s, and SCF_b indicate control (no fertilizer), surface placement of fertilizer, and bottom placement of fertilizer, respectively. Vertical bars represent standard errors (n = 9). Different lower case letters denote statistically significant differences among treatments ($\alpha = 0.05$; Duncan's multiple range test).

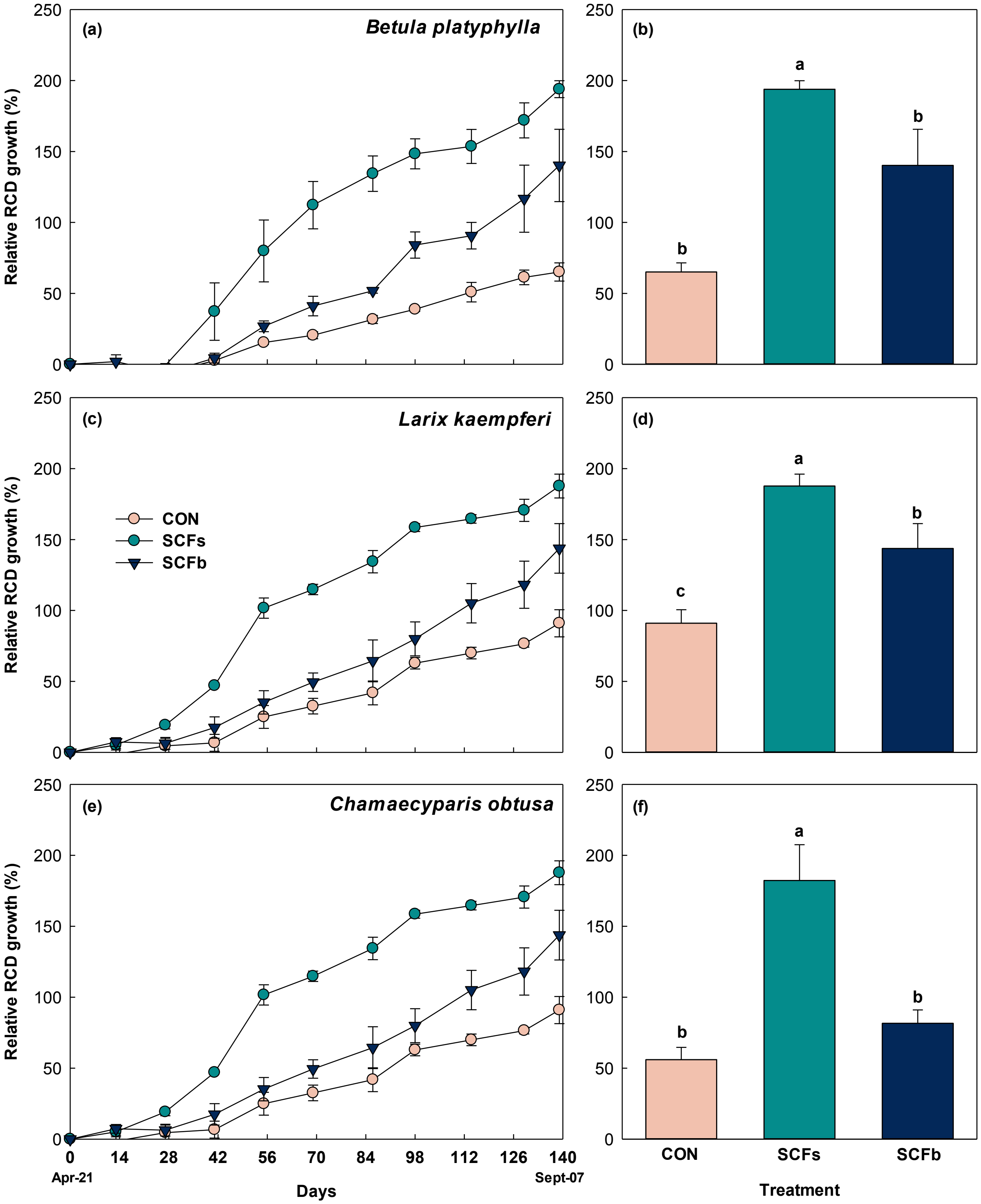

Figure 4. Root collar diameter (RCD) growth trends (a, c, e) of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa*, and the significant differences across the treatments at the end of the experiment (b, d, f). CON, SCF_s, and SCF_b indicate control (no fertilizer), surface placement of fertilizer and bottom placement of fertilizer, respectively. Vertical bars represent standard errors (n = 9). Different lower case letters denote statistically significant differences among treatments ($\alpha = 0.05$; Duncan's multiple range test).

Table 3. Coefficients of relative height and root collar diameter (RCD) growth rates of each species and treatment across time (day) based on the simple linear regression model (f(x) = ax, x is day (time) after treatment).

Species	Treatment	Relative height growth		Relative RCD growth	
		coefficient (a)	R^2	coefficient (a)	R^2
Betula	CON	0.53^b	0.85	0.43^c	0.84
platyphylla	SCF_s	1.53^a	0.92	1.33^a	0.93
	SCF_b	0.69^b	0.90	0.74^b	0.82
Larix	CON	0.21^b	0.91	0.59^b	0.91
kaempferi	SCF_s	0.95^a	0.97	1.44^a	0.93
	SCF_b	0.40^b	0.84	0.87^b	0.89
Chamaecyparis	CON	0.29^b	0.90	0.38^b	0.77
obtusa	SCF_s	0.54^a	0.93	1.11^a	0.87
	SCF_b	0.29^b	0.95	0.48^b	0.67

The significance of the model and coefficient is $p < 0.001$ (n = 9). Different lowercase letters denote statistically significant differences between treatments within species at $\alpha = 0.05$.

weight did not change but the NPK concentrations and contents increased in SCF_s, indicating luxury consumption of N nutrients (vector D in Figure 2); in SCF_b, foliar dry weight and N nutrient contents and concentrations increased, indicating deficiency or limiting (vector C in Figure 2). The NPK in *L. kaempferi* was also diagnosed as deficient or limiting in all fertilizer placement treatments. In *C. obtusa*, nutrient N and P were diagnosed as limiting in both SCF_s and SCF_b, but element K reflected sufficiency in SCF_s and dilution in SCF_b treatments (vector B and A in Figure 2, respectively).

4. Discussion

4.1. Effects of different SCF placement application methods on growth and foliar nutrients

As our expectation, the relative height and RCD growth and total biomass of all species grown in SCF_s (subsurface placement) were significantly higher than those grown in the bottom-applied fertilizer (SCF_b) and CON, which can generally be attributed to the slow-release characteristic of the fertilizer used. In some studies, it has been reported that the application of slow-release fertilizers can reduce nutrient leaching and improve water use efficiency (Gholamhoseini et al., 2013; Zareabyaneh and Bayatvarkeshi, 2015), thereby increasing plant uptake. Another factor that can elucidate the effectiveness of SCF_s is nutrient volatilization. For example, Ribeiro et al. (2016) reported that the application of a slow-release N fertilizer at 2–3 cm deep on the surface resulted in lower ammonia volatilization (i.e., 13.9% loss) compared to the other treatments (i.e., 19.6% loss). A 50% loss of applied N due to volatilization was also observed when the fertilizer was spread on the soil surface but tended to decrease when the fertilizer was covered or incorporated with soil (Rochette et al., 2013).

The lower growth performance observed from the bottom-applied SCF fertilizer can also be explained by the slow release property of the SCF. Although volatilization is less evident at deep-applied fertilizer (Ribeiro et al., 2016) compared to the shallow-incorporated ones, the uptake of nutrients in SCF_b may have occurred much slower than that in SCF_s due to the distance of the SCF granules from the root system of the planted seedlings. In this study, we applied the SCF granules at 35 cm deep for SCF_b, which seemed to have been too far from the root system of seedlings in early phase of planting compared to those at subsurface-applied fertilizer treatment. This can explain the longer root length observed at SCF_b than those at SCF_s at the end of the experiment period in all species, which can be ascribed to the re-direction of root growth toward a nutrient-rich part of the soil, also known as chemotropism of roots (Deng et al., 2017; Dao et al., 2020; Muthert et al., 2020). The observed higher belowground biomass growth and allocation of seedlings grown in SCF_b exemplifies developmental plasticity of root architecture, which is a form of nutrient acquisition strategy or a chemotropism response of plants (Niu et al., 2013). In contrast, seedlings grown under SCF_s need not make their roots longer and larger because nutrients are readily available for plant uptake. In the case of the slow-growing *C.obtusa*, root length at SCF_b was similar to that of CON, which can support the theory on plant growth

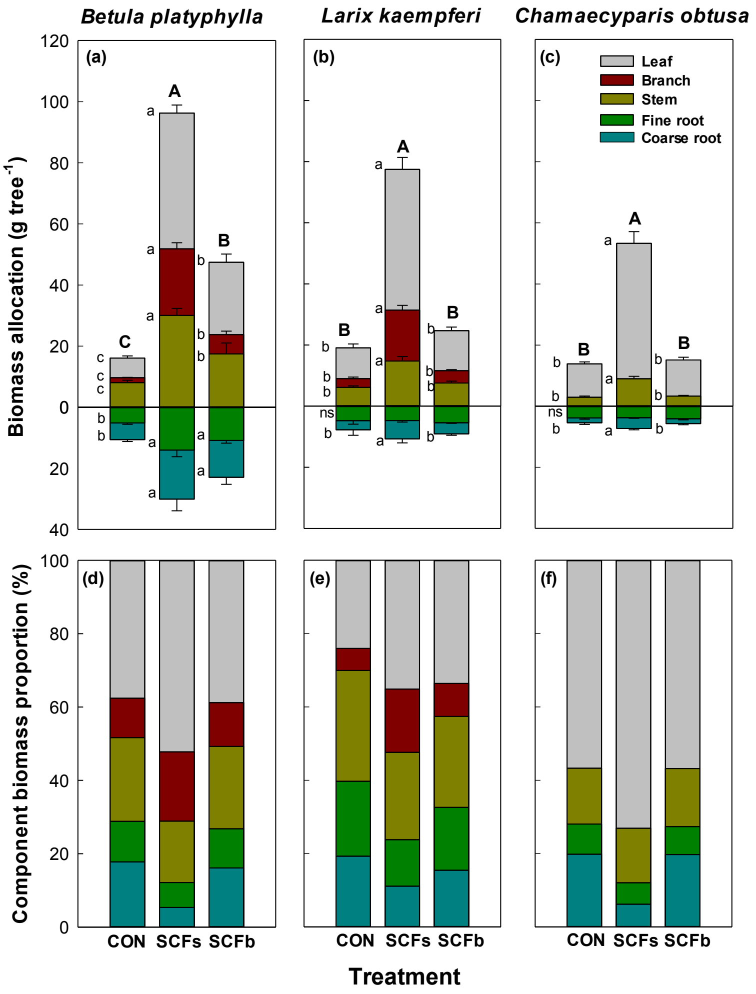

Figure 5. Biomass growth (a, b, and c) and proportion of each component (d, e, and f) of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa* applied with solid compound fertilizer. CON, SCF$_s$, and SCF$_b$ indicate control (no fertilizer), surface placement of fertilizer, and bottom placement of fertilizer, respectively. Vertical bars represent standard errors (n = 9). Different upper (total biomass) and lower (leaf, branch, stem, coarse root, fine root biomass) case letters denote statistically significant differences among treatments (α = 0.05; Duncan's multiple range test).

strategy of slow-growing species. This group of species produce less roots with lower absorptive capacity than that of fast-growing species (Comas et al., 2002). This can be seen in the descending order of root length observed across the three studied species, that is, *B. platyphylla* (fast-growing) > *L. kaempferi* (fast-growing) > *C.obtusa* (slow-growing). Slow-growing seedlings also have lower rates of nutrient requirements and steady sate of uptake regardless of nutrient availability in the soil than fast-growing ones (Chapin 1980, Funk 2008).

In terms of nutrient uptake, SCF$_s$ resulted in the highest N content in leaves of all species across the treatments. Vector analysis also showed that nutrient status in SCF$_b$ treatment was generally diagnosed as nutrient deficient. In addition to the general characteristics of a slow-release type of fertilizer, results on nutrient response can be due to the watering events which may have facilitated the solubility of the SCF fertilizer in the subsurface, thereby improving the N-mineralization and adsorption rates. This can be seen in the observed foliar nutrient level of seedlings under SCF$_s$, that is, luxury consumption of NPK nutrients of *B. platyphylla* but still within the sufficiency range and is non-toxic. It was also reported that N-mineralization rates decreased not only with increasing soil depths but also with increasing soil moisture, that is, half and fully-saturated soil resulted in significantly higher N-mineralization than that in control (Fu-Sheng et al., 2005).

4.2. Implications for increasing tree growth and survivability

In general, the observed improved growth and N uptake of seedlings grown under SCF$_s$ for all species are important findings relevant not only to improving growth but also

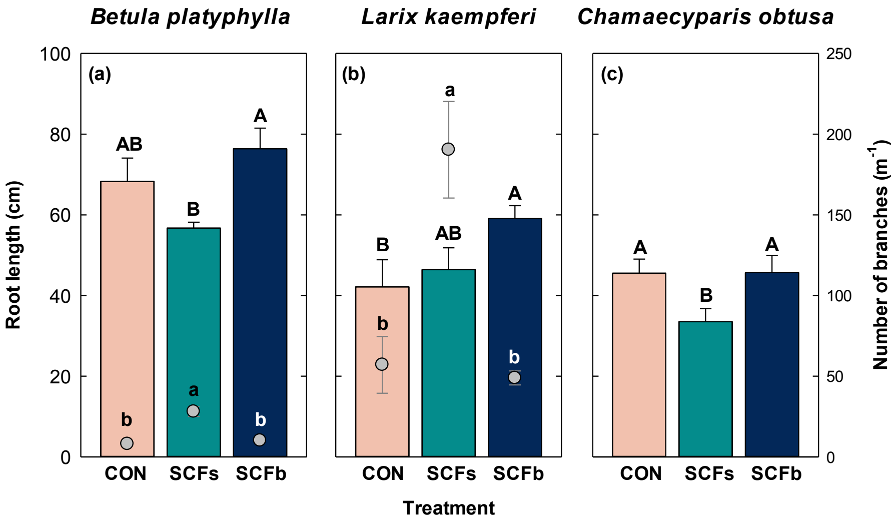

Figure 6. Root length (cm) and number of branches (m^{-1}) of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa* applied with solid compound fertilizer. CON, SCF$_s$, and SCF$_b$ indicate control (no fertilizer), surface placement of fertilizer, and bottom placement of fertilizer, respectively. Number of branches were not measured for *C. obtusa*. Vertical bars represent standard errors (n = 9). Different upper (root length) and lower (number of branches) case letters denote statistically significant differences among treatments ($\alpha = 0.05$; Duncan's multiple range test).

Table 4. Nitrogen (N), phosphorus (P), and potassium (K) concentrations (%) in leaf of *Betula platyphylla, Larix kaempferi*, and *Chamaecyparis obtusa* applied with solid compound fertilizer at different positions. CON, SCF$_s$, and SCF$_b$ indicate control (no fertilizer), and surface and bottom placements of fertilizer, respectively. Standard errors are in parentheses (n = 3). Different lower case letters denote statistically significant differences among treatments within species ($\alpha = 0.05$; Duncan's multiple range test).

Species	Treatment	N		P		K	
Betula platyphylla	CON	1.29	(0.06)^{b}	1.75	(0.80)	0.45	(0.02)
	SCF$_s$	2.84	(0.02)^{a}	2.51	(0.56)	0.60	(0.10)
	SCF$_b$	1.39	(0.07)^{b}	2.17	(0.41)	0.54	(0.08)
Larix kaempferi	CON	0.93	(0.07)^{c}	1.60	(0.19)	0.42	(0.06)
	SCF$_s$	2.02	(0.04)^{a}	2.36	(0.46)	0.48	(0.12)
	SCF$_b$	1.24	(0.03)^{b}	2.48	(0.32)	0.53	(0.11)
Chamaecyparis obtusa	CON	1.22	(0.03)^{b}	2.45	(0.32)	0.58	(0.16)
	SCF$_s$	1.88	(0.07)^{a}	2.78	(0.31)	0.58	(0.02)
	SCF$_b$	1.39	(0.08)^{b}	2.85	(0.13)	0.47	(0.09)

to increasing survival of seedlings, especially in marginal lands. For example, the illustrated good performance of the three species in SCF$_s$ is relevant to fertilizing trees or newly-planted seedlings in steep slope and soil erosion-prone areas. Using such a placement method can provide more binding sites for nutrients in the soil, thereby reducing exposure to surface runoff and nutrient loss, especially during high rainfall events. Also, because SCF generally releases nutrients into the environment in a slow or controlled manner, SCF$_s$ placement can, therefore, be employed in areas with high porosity soils and high irrigation to improve fertilizer retention over a long period of time.

The observed higher belowground biomass or higher root length of all species grown in SCF$_b$ compared to subsurface-applied ones is an interesting result of the study. In a forest setting, mechanical forces acting on steep slopes tend to overturn plants, which respond by developing asymmetrical root architecture that increases the plant's stability and root efficiency (Chiatante et al., 2003). Moreover, the ability to exhibit plasticity or re-direction in root growth toward the nutrient-rich zone of the soil, through chemotropism, can be considered an important adaptive mechanism of all species grown in the bottom-applied fertilizer. This mechanism can further help

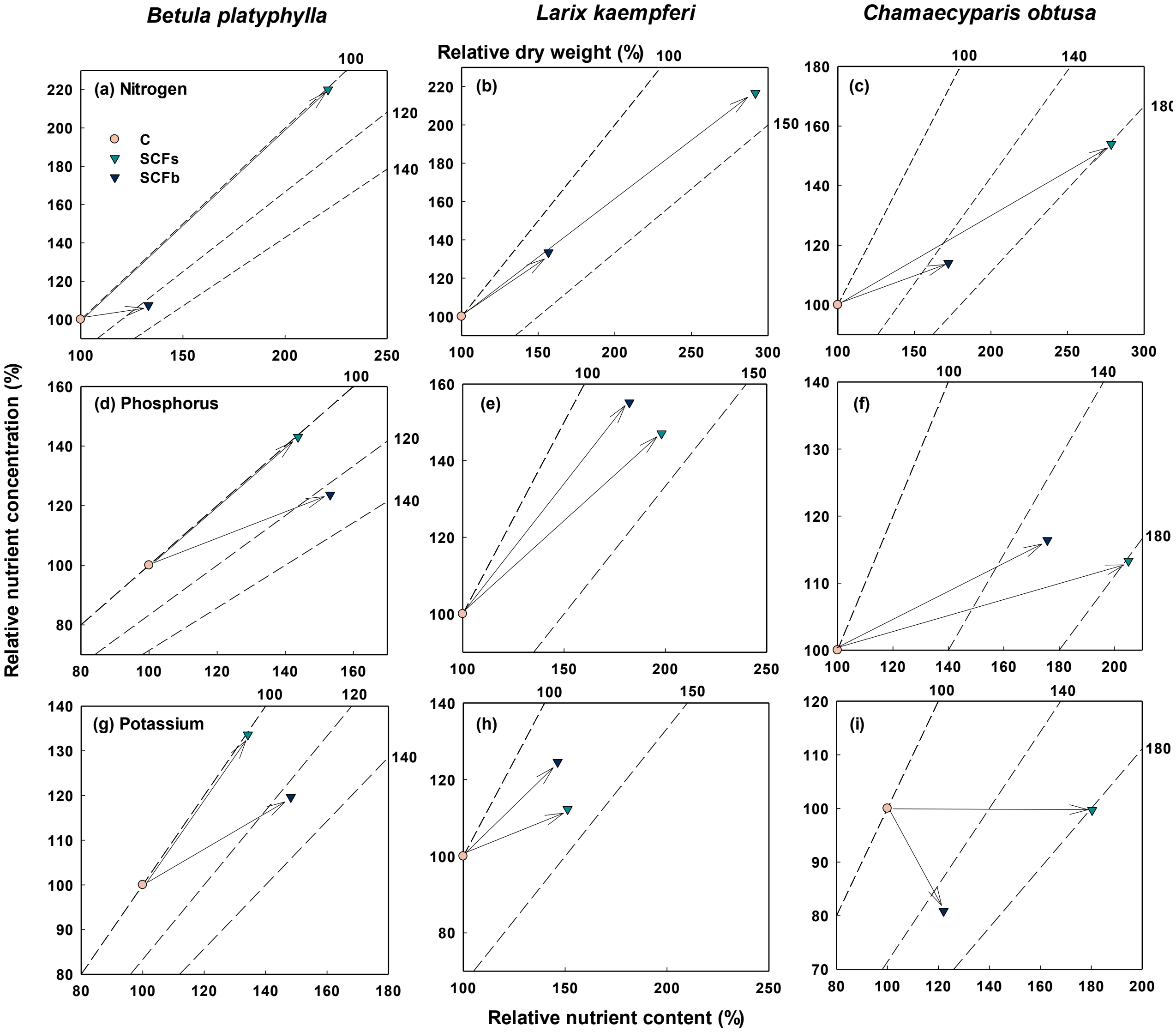

Figure 7. Vector diagnosis for nitrogen (a, b, and c), phosphorus (d, e, and f), and potassium (g, h, and i) in leaf of *Betula platyphylla*, *Larix kaempferi*, and *Chamaecyparis obtusa* applied with solid compound fertilizer. CON, SCF_s, and SCF_b indicate control (no fertilizer), surface placement of fertilizer, and bottom placement of fertilizer, respectively.

in nutrient acquisition, especially in poor soil conditions typical of marginal lands.

The branch production was also higher in SCF_s for both *L. kaempferi* and *B. platyphylla*, suggesting that such placement tended to increase aboveground growth while reducing the belowground growth. However, from a silviculture viewpoint, significantly higher aboveground growth relative to belowground growth does not always exemplify better plant growth; hence, operational cutting of branches may also be done to improve the root: shoot growth of the fast-growing species under SCF_s fertilization.

Lastly, the fastest RCD and height growth occurred between the 42nd and 56th day periods (i.e., offset of spring to early summer) in three species. This information is important for forest managers to efficiently calendar their fertilization activities for the three studied species to insure that application of SCF is effective for tree growth and survival. This is because plants of different growth rates respond differently to fertilizer due to differences in nutrient demands and fertility targets (Salifu et al., 2009).

5. Conclusion

The different placement methods of SCF application all resulted in improved plant growth and foliar N uptake, but the magnitude of the effect varied significantly across the treatments in all species. Under a greenhouse experiment, SCF_s has shown to be the most effective placement method of SCF application for increasing aboveground biomass and nutrient (N) acquisition, while SCF_b was the placement effective for increasing root length and root biomass growth in all species. Results are relevant to the promotion of ecofriendly and cost-effective approach of increasing the growth and survival of economically important forest tree species, especially in steep slope and erosion-prone areas or marginal forest lands. Moreover, our findings can help forest managers synchronize the release of nutrients with the demands of forest tree species and site conditions.

Acknowledgment

The authors would like to thank the following researchers, W.B. Youn, A. Aung, S.H. Han, and J.O. Hernandez for their help in the data collection and tree biomass investigation.

Funding

This study was carried out with the support of 'R&D Program for Forest Science Technology (Project No. 2020184C10-2020-AA02 and 2021379A00-2123-BD02)' provided by Korea Forest Service (Korea Forestry Promotion Institute) and the research Fund by Chungam National University.

References

Alam M, Bell R, Salahin N, Pathan S, Mondol A et al. (2018). Banding of fertilizer improves phosphorus acquisition and yield of zero tillage maize by concentrating phosphorus in surface soil. Sustainability 10 (9): 3234. doi: 10.3390/su10093234

Aung A, Seo JM, Han SH, An JY, Dao HTT et al. (2020). Effects of torrefied wood chip and vermicompost application on vegetation growth and nutrient uptake in the Saemangeum reclaimed land. Ecol Process 9: 7. doi: 10.1186/s13717-020-0212-6

Baker DB, Richards RP (2002). Phosphorus budgets and riverine phosphorus export in northwestern ohio watersheds. Journal of Environment Quality 31 (1): 96. doi: 10.2134/jeq2002.0096

Bakhtiari MR, Ghahraei O, Ahmad D, Yazdanpanah AR, Jafari AM (2014). Selection of fertilization method and fertilizer application rate on corn yield. Agricultural Engineering. International CIGR Journal 16: 10-14.

Bittman S, Liu A, Hunt D, Forge T, Kowalenko C et al. (2012). Precision placement of separated dairy sludge improves early phosphorus nutrition and growth in corn (*Zea mays* L.). Journal of Environmental Quality 41 (2): 582-591. doi: 10.2134/jeq2011.0284

Bown HE, Watt MS, Clinton PW, Mason EG, Whitehead D (2009). The influence of N and P supply and genotype on carbon flux and partitioning in potted *Pinus radiata* plants. Tree Physiology 29 (7): 857-868. doi: 10.1093/treephys/tpp030

Castillo MM (2010). Land use and topography as predictors of nutrient levels in a tropical catchment. Limnologica 40 (4): 322-329. doi: 10.1016/j.limno.2009.09.003

Chapin FS III (1980). The mineral nutrition of wild plants. Annual Review of Ecology and Systematics 11: 233-260.

Chiatante D, Scippa SG, Iorio AD, Sarnataro M (2003). The influence of steep slopes on root system development. Journal of Plant Growth Regulation 21 (4): 247-260. doi: 10.1007/s00344-003-0012-0

Cáceres CB, Hernández RE, Fortin Y (2018). Variation in selected mechanical properties of Japanese larch (*Larix kaempferi*, [Lamb.] Carr.) progenies/provenances trials in Eastern Canada. European Journal of Wood and Wood Products 76 (4): 1121-1128. doi: 10.1007/s00107-018-1302-3

Comas L, Bouma T, Eissenstat D (2002) Linking root traits to potential growth rate in six temperate tree species. Oecologia 132 (1): 34-43.

Dao HTT, Seo JM, Hernandez JO, Han SH, Youn WB et al. (2020). Effective placement methods of vermicompost application in urban tree species: implications for sustainable urban afforestation. Sustainability 12 (14): 5822. doi: 10.3390/su12145822

Deng S, Yin Q, Zhang S, Shi K, Jia Z et al. (2017). Drip irrigation affects the morphology and distribution of olive Roots. HortScience 52 (9): 1298-1306. doi: 10.21273/hortsci11997-17

Ebrahimi E, Ghorbani R, Niemsdorff PVFU (2019). Effects of vermicompost placement on nutrient use efficiency and yield of tomato (*Lycopersicum esculentum*). Biological Agriculture & Horticulture 36 (1): 44-52. doi: 10.1080/01448765.2019.1671220

Funk J L 2008. Differences in plasticity between invasive and native plants from a low resource environment. Journal of Ecology 96 (6): 1162-1173.

Fu-Sheng C, De-Hui Z, Narain SA, Guang-Sheng C (2005). Effects of soil moisture and soil depth on nitrogen mineralization process under Mongolian pine plantations in Zhanggutai sandy land, P. R. China. Journal of Forestry Research 16 (2): 101-104. doi: 10.1007/bf02857899

Gholamhoseini M, Ghalavand A, Khodaei-Joghan A, Dolatabadian A, Zakikhani H (2013). Zeolite-amended cattle manure effects on sunflower yield, seed quality, water use efficiency and nutrient leaching. Soil and Tillage Research 126: 193-202. doi: 10.1016/j.still.2012.08.002

Hafsi C, Atia A, Lakhdar A, Debez A, Abdelly C (2011). Differential responses in potassium absorption and use efficiencies in the halophytes *Catapodium rigidum* and *Hordeum maritimum* to various potassium concentrations in the medium. Plant Production Science 14 (2): 135-140. doi: 10.1626/pps.14.135

Haase DL, Rose R (1995). Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. Forest Science 41: 54-66.

Kronvang B, Jeppesen E, Conley DJ, Søndergaard M, Larsen SE et al. (2005). Nutrient pressures and ecological responses to nutrient loading reductions in Danish streams, lakes and coastal waters. Journal of Hydrology 304 (1-4): 274-288. doi: 10.1016/j.jhydrol.2004.07.035

Mallin MA, Johnson VL, Ensign SH, Macpherson TA (2006). Factors contributing to hypoxia in rivers, lakes, and streams. Limnology and Oceanography 51: 690-701. doi: 10.4319/lo.2006.51.1_part_2.069

Miller BD, Hawkins BJ (2007). Ammonium and nitrate uptake, nitrogen productivity and biomass allocation in interior spruce families with contrasting growth rates and mineral nutrient preconditioning. Tree Physiology 27 (6): 901-909. doi: 10.1093/treephys/27.6.901

Muthert LWF, Izzo LG, Zanten MV, Aronne G (2020). Root tropisms: investigations on earth and in space to unravel plant growth direction. Frontiers in Plant Science 10. doi: 10.3389/fpls.2019.01807

Nadkarni N, Wheelwright NT (2000). Monteverde: Ecology and Conservation of a Tropical Cloud Forest. Oxford University Press.

Nielsen RL, James JJ, Drenovsky RE (2019). Functional traits explain variation in chaparral shrub sensitivity to altered water and nutrient availability. Frontiers in Plant Science 10: 505. 10. doi: 10.3389/fpls.2019.00505

Niu YF, Chai RS, Jin GL, Wang H, Tang CX et al. (2013). Responses of root architecture development to low phosphorus availability: a review. Annals of Botany 112 (2): 391-408. doi: 10.1093/aob/mcs285

Rahman KMA, Zhang D (2018). Effects of fertilizer broadcasting on the excessive use of inorganic fertilizers and environmental sustainability. Sustainability 10 (3): 759. doi: 10.3390/su10030759

Ramli RA (2019). Slow release fertilizer hydrogels: a review. Polymer Chemistry 10 (45): 6073-6090. doi: 10.1039/c9py01036j

Ribeiro VJ, Andrade FV, Souza CHED, Mendonça ES (2016). Volatilization of ammonia in stabilized slow-release nitrogen fertilizer under controlled conditions. Australian Journal of Crop Science 10 (6): 793-798. doi: 10.21475/ajcs.2016.10.06.p7283

Rochette P, Angers DA, Chantigny MH, Gasser MO, Macdonald JD et al. (2013). Ammonia volatilization and nitrogen retention: how deep to incorporate urea? Journal of Environmental Quality 42 (6): 1635-1642. doi: 10.2134/jeq2013.05.0192

Ryan J (2008). A perspective on balanced fertilization in the Mediterranean region. Turkish Journal of Agriculture and Forestry 32: 79-89.

Salifu KF, Jacobs DF, Birge ZKD (2009). Nursery nitrogen loading improves field performance of bareroot oak seedlings planted on abandoned mine lands. Restoration Ecology 17 (3): 339-349.

Sato A, Ishizuka M, Sugarawa S, Toyooka H (1986). Changes in the structure and the above-ground biomass of a young *Betula platyphylla* var. *japonica* stand on a peat soil. Journal of the Japanese Forestry Society 68: 205-207.

Sawata S, Kato H (1991). Effect of forest on soil (part 2). The base accumulation and other soil properties related to age of cryptomeria and Japanese cypress stands. Japanese Journal of Soil Science and Plant Nutrition 62: 49-58.

Sestak Z, Catsky J, Jarvis PG (1971). Plant photosynthetic production. Manual of methods. The Quarterly Review of Biology 47: 235-235.

Shen J, Li C, Mi G, Li L, Yuan L et al. (2013). Maximizing root/rhizosphere efficiency to improve crop productivity and nutrient use efficiency in intensive agriculture of China. Journal of Experimental Botany 64 (5): 1181-1192. doi: 10.1093/jxb/ers342

Stipešević B, Brozović B, Jug D, Jug I, Vukadinović V et al. (2019). Effects of tillage method and fertilizer type on the yield of Sudan grass (*Sorghum bicolor* L.). Turkish Journal of Agriculture and Forestry 43 (3): 378-387. doi: 10.3906/tar-1805-17

Timmer VR, Stone EL (1978). Comparative foliar analysis of young balsam fir fertilized with nitrogen, phosphorus, potassium, and lime. Soil Science Society of America Journal 42 (1): 125-130. doi: 10.2136/sssaj1978.03615995004200010027x

Ünlükara A (2019). Effects of depth-dependent irrigation regimes and organo mineral fertilizers on water use and quality attributes of sugar beet. Turkish Journal of Agriculture and Forestry 43: 492-499. doi: 10.3906/tar-1903-56

Zareabyaneh H, Bayatvarkeshi M (2015). Effects of slow-release fertilizers on nitrate leaching, its distribution in soil profile, N-use efficiency, and yield in potato crop. Environmental Earth Sciences 74 (4): 3385-3393. doi: 10.1007/s12665-015-4374-y

Zheng W, Liu Z, Zhang M, Shi Y, Zhu Q et al. (2017). Improving crop yields, nitrogen use efficiencies, and profits by using mixtures of coated controlled-released and uncoated urea in a wheat-maize system. Field Crops Research 205: 106-115. doi: 10.1016/j.fcr.2017.02.009