Growth Characteristics of Woody Plants by Soil Depth for Container Garden

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ABSTRACT

The appropriate soil depth for each species should be determined by taking into account the visual quality of the plant, including the growth conditions of the trees and total photosynthesis. The purpose of this study was to investigate the growth characteristics -height, root collar diameter, dry weight- and quality index according to soil depth. Therefore this study proposed suitable plants according to container size (soil depth) when creating a container garden. The result are as follows; *Pinus densiflora*, *Pinus parviflora* and *Nandina domestica* have poor growth and low ornamental value at 15 cm depth. Therefore, they will be available at a minimum depth of 20 cm. *Thuja occidentalis* grew in 15 cm of soil depth and had a normal visual value, but it was desirable to plant 20 cm of soil depth. *Ilex serrata* grew at least 20 cm above depth but it was not suitable for container garden because of its low value of ornamental value. *Syringa vulgaris* had little difference in growth depending on soil depth. Considering the visual quality, it will be possible to plant for container gardening at a soil depth of 20 cm or more. Container gardens are an alternative to forming green spaces in places where planting is difficult in the city. Therefore, appropriate containers and plants should be selected.

Keywords: container gardening, planting materials, roadside garden, urban space

Introduction

The population ratio of urban areas in 2016 is 91.82%, which shows that about 92% of the entire population is living in urban areas (residential, commercial, industrial, green areas) in terms of use zoning. It is annually increasing from 90.1% in 2005, and the index by Statistics Korea expects constant growth in the future as well (Statistics Korea, 2017). Development has been continuously made as the population is concentrated into the cities, and natural environments including green spaces are disappearing in this process. Recently there have been active movements to find or create natural environments in the city as their importance is being emphasized as restorative environment. However, it is difficult to find the appropriate space in areas not designated as parks or greens by use zoning. To solve this problem, it has become an alternative to use artificial ground like rooftop and vertical greening or create stereoscopic green space.

In particular, urban street space is a public space used by many people, but it is difficult to secure green spaces that provide amenity, aesthetics and ecological property. Since streets perform a key role in determining urban image by

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building the frame of the city, it is important to implement greens in street space. To this end, natural elements like street trees, flowerbeds and flower pots are actively implemented.

Container gardens where plants are cultivated in containers can plant a variety of different plants considering aesthetics and functionality because they can provide the planting base in a space that cannot secure planting space (Oh, 2013). Most local governments create container gardens in streets where planting is difficult. Seoul invested 21.256 billion KRW from 2008 to 2020 to create year-round flower streets (hanging flowerpots, street flowerpots, theme flower gardens, etc.) around areas with a lot of traffic in the city and areas that are visually poor (Seoul Metropolitan Government, 2017). Other local governments are also investing human resources and budgets into replacing plants while considering annual changes of the seasons. Most container gardens managed by local governments are annual plants with long flowering duration and distinct colors, with great consideration of the aesthetic aspect. On the other hand, for private spaces that are not containers in public spaces, green areas are formed mostly with evergreens but with minimized maintenance. In this aspect, it is necessary to select adequate plants according to the locational properties and functions of container gardens.

Various factors are to be considered in implementing plants for container gardens in the urban environment, but so far studies on container gardens have been focused on aesthetics such as floral designs to improve the urban environment (Kim, 2008), types and designs of plants on roadside flowerbeds (Byun, 2012), and public urban design applying flowering plants (Kim, 2010). However, it is also important to create an environment for plants to grow well in container gardens. The limited amount of soil in urban trees fails to sufficiently fulfill the needs for evapotranspiration, thereby resulting in poor survival and growth of trees (DeGratano, 2000). In other words, physical properties such as moisture content of soil, density, air permeability and temperature as well as chemical features such as pH, fertility and salinity affect the growth of plants (Thorup, 1969; Adams et al., 1967; Mergel et al., 1974; Gerard et al., 1982). Moreover, unlike plants that are planted in the ground, container gardens are planted in limited space, thereby requiring constant replacement of containers due to the plant growth. Container gardens in the urban environment provide amenity to the urban environment and visual satisfaction to urban dwellers, and thus they must be maintained so that their aesthetics are not deteriorated. Maintenance must take financial aspects into account, including proper overhead flooding, fertilization management, grading and pruning, as well as selection of plants to grow well in limited containers and constant replacement.

Therefore, this study intends to provide basic data required for maintaining growth health of woody plants while considering aesthetics and economic feasibility in creating container gardens at an initial stage by determining the growth characteristics of plants for soil depth of each container size.

Research Method

Plants for experiment

This study is to determine appropriate soil depth for plant growth to implement container gardens, and selected plants for experiment according to the following criteria. The container garden must be located outdoors and satisfy both aesthetic and functional requirements such as landscape viewing and area setting, thereby maintaining consistent form year-round. Moreover, since it is created on the roadside where people walk by, it must not have elements that cause displeasure or threat to passersby. Considering these criteria and the current building status of container gardens, the arbors that form the frame of the container gardens were selected from species that can grow in the south-central region among evergreens that can maintain a fixed shape and consistent form year-round and are strong against grading and pruning. The shrubs were selected from species that are currently used a lot in roadside flowerbeds and can be seen

year-round. Ultimately, the arbors used in the study were *Thuja occidentalis*, *Pinus densiflora*, and *Pinus parviflora*, and the shrubs used were *Ilex serrata*, *Nandina domestica*, and *Syringa vulgaris* (Table 1).

Method of experiment

To analyze the growth characteristics of plants according to container soil depth, this study created the plot on the open ground in the National Institute of Horticultural & Herbal Science. In May 2015, 6 plants of three-year-old species in the same size were planted in each of the three types of containers with different heights (Table 2). Container gardens are similar to the environment of artificial ground, where soil and drainage conditions as well as the container material are not in natural state, and thus soil depth was set up with reference to the rooftop greening criteria. The Landscape Architecture Design Criteria (KILA, 2013) classified it into 15 cm and 30 cm lower and higher than the minimum soil depth for survival, which is 20 cm, in the artificial ground for shrubs. Soil used in the study is nursery bed soil (Sunshine mix 4, Sun Gro Horticulture, Canada, peat moss 60-70%, perlite 30-40%). Watering was done once a week after plantation, and 100 g of slow-acting manure (Osmocote, Scotts, USA, 11-11-17+2MgO+TE) was fertilized every year. Pesticides and germicides were sprayed twice in summer to prevent spasmodic diseases and insect pests.

Measurement and analysis methods

Plant height and plant root collar diameter were measured to investigate growth characteristics according to soil depth. Plant height was measured since 60 days after plantation every 30 days from July to November 2015 and April to October 2016, from ground surface to the highest part of the stem. Plant root collar diameter was also measured on the same day of the stem just above the ground surface using calipers. For plant height and plant root collar diameter, this study estimated monthly relative growth by dividing growth variation (difference between the growth at the end of the experiment and the growth at the beginning of plantation) by the number of growth days (term from plantation to the end of experiment). After the experiment was over in November 2016, dry weight for branch and root was measured. Quality index was evaluated to

Table 1. Growth characteristics of species at the planting.

Species	Height (cm)	Root collar diameter (mm)
<i>Thuja occidentalis</i>	20±2.1	2.0±0.5
<i>Pinus densiflora</i>	25±3.5	6.5±0.6
<i>Pinus parviflora</i>	30±2.5	5.0±0.8
<i>Ilex serrata</i>	30±3.7	2.0±0.7
<i>Nandina domestica</i>	18±3.4	1.3±0.4
<i>Syringa vulgaris</i>	35±3.7	3.2±0.9

Table 2. Characteristics of containers.

Soil depth (cm)	Size (cm)			Volume (L)	Material
	Length	Width	Height		
15	64	47	18.5	45	plastic
20	64	47	28.5	60	plastic
30	64	47	40	90	plastic

determine the ornamental value of the trees. For the quality index, overall growth condition, occurrence of dead branches, discoloration of leaves, and fallen leaves are rated on a five-point scale from poor (1 point) to good (5 point). Measured data were analyzed with SPSS ver. 12.0. Since data quantity is small, non-parametric methods such as the Kruskal–Wallis test and Mann-Whitney U test were used to evaluate the significance according to soil depth.

Results and Discussions

Growth characteristics

Plant height

An analysis of monthly plant height shows that arbors such as *Thuja occidentalis* and *Pinus densiflora*, *Pinus parviflora* showed in significant growth for a year after transplanting, but grew rapidly since 310 days. On the other hand, unlike arbors, shrubs such as *Ilex serrata*, *Nandina domestica*, and *Syringa vulgaris* showed constant growth in plant height since

Figure 1. The growth patterns of plant height by three types of soil depth.

A=*Thuja occidentalis*; B=*Pinus densiflora*; C=*Pinus parviflora*; D=*Ilex serrata*; E=*Nandina domestica*; F=*Syringa vulgaris*.

transplanting. Among the arbors, *Thuja occidentalis* and *Pinus densiflora* had similar plant height at around 70 cm, but *Pinus parviflora* has shorter plant height than the other two. *Thuja occidentalis* showed a difference in soil depth as the growth period got longer, growing tallest when soil depth was 20 cm but with not much difference from 30 cm. After 370 days of growth, there was no difference between 20 cm and 30 cm, but 15 cm showed a statistically significant difference (kruskal-wallis $X^2=7.60$, $p<.05$). *Pinus densiflora* showed almost no difference in 20 cm and 30 cm, but growth stopped and the plant died after July for 15 cm. *Pinus parviflora* showed tall plant height in 30 cm but with not much difference from 20 cm. It showed similar growth characteristics with 30 cm in 15 cm soil depth, but growth decreased since 400 days. Among the shrubs, *Ilex serrata* and *Nandina domestica* grew to around 80cm and *Syringa vulgaris* to around 70 cm. *Ilex serrata* and *Nandina domestica* showed slower growth or died after 400 days in 15 cm soil depth. Therefore, growth may be possible only when soil depth is at least 20 cm. On the other hand, *Syringa vulgaris* showed similar growth regardless of soil depth, suggesting that the effect of soil depth on growth is insignificant. *Thuja occidentalis*, *Pinus densiflora*, *Pinus parviflora*, *Ilex serrata*, and *Nandina domestica* can be grown in at least 20 cm soil depth, and *Syringa vulgaris* in at least 15 cm (Fig. 1).

As for relative growth of plant height, *Thuja occidentalis* among arbors and *Nandina domestica* among shrubs showed high relative growth, whereas *Pinus parviflora* showed relatively low speed in growth. In particular, *Pinus densiflora* showed almost no growth in 15 cm. In terms of statistical significance, *Thuja occidentalis* and *Pinus densiflora* showed similar growth speed in 20 cm and 30 cm soil depth, which implies that they can grow in 20 cm soil depth as well. *Ilex serrata* and *Syringa vulgaris* showed no statistical significance but similar growth speed regardless of soil depth, and thus can be grown in 15 cm, while *Nandina domestica* can be grown in at least 20 cm soil depth (Table 3).

Plant root collar diameter

Plant root collar diameter is showing similar growth characteristics as plant height. *Thuja occidentalis*, *Pinus densiflora*, and *Pinus parviflora* showed insignificant growth until 310 days after transplanting, but since then growth increased actively. *Thuja occidentalis* and *Pinus densiflora* showed similar growth in 20 cm and 30 cm soil depth. *Pinus densiflora* died in 15 cm soil death after 400 days (July 2016), and the death in summer may have been caused by low moisture content of soil. At least 20 cm soil depth must be secured considering plant root collar diameter. *Pinus parviflora* showed high growth in 30 cm but had no statistical difference according to soil depth, which suggests that it can be grown in 15 cm soil depth as well. *Ilex serrata* and *Nandina domestica* show similar growth patterns in 20 cm and 30 cm, but died

Table 3. Monthly relative growth ratio of height by soil depth.

Species	Height by soil depth (cm)			Kruskal-Wallis test
	15 cm	20 cm	30 cm	
<i>Thuja occidentalis</i>	2.4±0.39 b ^z	3.7±0.30 a	3.3±0.41 a	12.251**
<i>Pinus densiflora</i>	0.4±0.29 b	2.9±0.73 a	2.8±0.64 a	11.439**
<i>Pinus parviflora</i>	2.0±0.65 a	1.5±0.55 a	1.9±1.52 a	1.163
<i>Ilex serrata</i>	2.9±1.11 a	2.8±0.79 a	2.8±0.66 a	0.091
<i>Nandina domestica</i>	2.5±1.38 a	3.8±1.15 a	3.6±1.60 a	2.549
<i>Syringa vulgaris</i>	2.2±0.80 a	2.1±0.79 a	2.6±0.69 a	1.181

^zThe same letter on the row for each trees and index is not significantly different based on Mann-whitney U test at 5% level; ** $p<.01$, * $p<.05$.

after 400 days in 15 cm. Like *Pinus densiflora*, this may be due to the fact that soil moisture cannot be secured in 15cm soil depth. On the other hand, *Syringa vulgaris* showed similar growth regardless of soil depth (Fig. 2).

As for relative growth of plant root collar diameter, only *Pinus densiflora* and *Syringa vulgaris* had a statistically significant difference according to soil depth. *Pinus densiflora* showed no difference in growth in 20 cm and 30 cm soil depth, indicating that it can grow in at least 20 cm. *Syringa vulgaris* had high relative growth in 15 cm, which shows that it can grow in at least 15 cm. *Thuja occidentalis*, *Pinus parviflora*, *Ilex serrata*, and *Nandina domestica* showed no significant difference in relative growth according to soil depth (Table 4). However, at least 20 cm soil depth must be secured considering monthly growth.

Biomass

As a result of measuring dry weight by dividing the plants into above ground part and underground part to analyze the difference in photosynthesis output according to soil depth, it was found that *Thuja occidentalis* was relatively heavier

Figure 2. The growth patterns of plant root collar diameter by three types of soil depth.

A=*Thuja occidentalis*, B=*Pinus densiflora*; C=*Pinus parviflora*; D=*Ilex serrata*; E=*Nandina domestica*; F=*Syringa vulgaris*.

Table 4. Monthly relative growth ratio of root collar diameter by soil depth.

Species	Root collar diameter by soil depth (cm)			Kruskal-Wallis test
	15 cm	20 cm	30 cm	
<i>Thuja occidentalis</i>	0.12±0.026 a ^z	0.12±0.018 a	0.14±0.034 a	2.538
<i>Pinus densiflora</i>	0.02±0.005 b	0.08±0.018 a	0.08±0.031 a	11.536**
<i>Pinus parviflora</i>	0.07±0.024 a	0.07±0.032 a	0.07±0.029 a	0.012
<i>Ilex serrata</i>	0.07±0.017 a	0.08±0.027 a	0.08±0.024 a	1.976
<i>Nandina domestica</i>	0.07±0.015 a	0.07±0.013 a	0.09±0.029 a	4.667
<i>Syringa vulgaris</i>	0.09±0.021 a	0.07±0.014 ab	0.05±0.013 b	8.230**

^zThe same letter on the row for each trees and index is not significantly different based on Mann-whitney U test at 5% level; ** $p < .01$, * $p < .05$.

above ground than underground, whereas *Pinus parviflora*, *Ilex serrata*, *Nandina domestica*, and *Syringa vulgaris* did not show much weight difference. In other words, *Thuja occidentalis* has relatively weaker development of the root underground compared to above ground. Shrubs such as *Ilex serrata*, *Nandina domestica*, and *Syringa vulgaris* have similar weight between above ground and underground parts in 30 cm soil depth and thus are likely to have favorable adaptability to environmental changes such as wind or watering. *Thuja occidentalis*, *Pinus densiflora*, *Pinus parviflora*, *Nandina domestica*, and *Syringa vulgaris* had great weight in 30 cm for both above ground and underground, but *Ilex serrata* was heavy in 20 cm, showing growth differences (Fig. 3). Since container gardens must maintain consistent form for ornamental purpose or landscaping rather than production, it is necessary to choose soil depth that maintains a consistent level of growth rather than quick growth.

As for total dry weight, *Pinus densiflora*, *Ilex serrata*, and *Nandina domestica* have a statistically significant difference

Figure 3. The dry weight of plant by three types of soil depth.

A=*Thuja occidentalis*; B=*Pinus densiflora*; C=*Pinus parviflora*; D=*Ilex serrata*; E=*Nandina domestica*; F=*Syringa vulgaris*.

Table 5. The dry weight of plant by soil depth.

Species	Dry weight by soil depth (g)			Kruskal-Wallis test
	15 cm	20 cm	30 cm	
<i>Thuja occidentalis</i>	160.0±41.77 a ^z	175.0±53.36 a	185.0±75.98 a	0.433
<i>Pinus densiflora</i>	5.0±3.00 b	166.7±75.30 a	221.7±160.56 a	11.439**
<i>Pinus parviflora</i>	100.0±60.20 a	101.7±46.66 a	143.3±88.04 a	0.924
<i>Ilex serrata</i>	28.3±14.92 b	95.0±28.11 a	68.3±28.50 b	10.842**
<i>Nandina domestica</i>	16.7±13.48 b	96.7±70.49 a	130.0±71.78 a	10.388**
<i>Syringa vulgaris</i>	143.3±81.00 a	166.7±113.11 a	186.7±140.81 a	0.035

^zThe same letter on the row for each trees and index is not significantly different based on Mann-whitney U test at 5% level; ** $p < .01$, * $p < .05$.

according to soil depth. *Pinus densiflora* and *Nandina domestica* had relatively low dry weight in 15 cm, but showed no statistical difference in 20 cm and 30 cm. On the other hand, *Ilex serrata* was relatively high in 20 cm (Table 5). Considering photosynthesis output, 20 cm soil depth will also be appropriate for *Ilex serrata*, and *Pinus densiflora* and *Nandina domestica* can grow only when soil depth is at least 20 cm.

Quality characteristics

Container gardens are not for cultivation or production of trees but for aesthetics, and thus it is important to visually determine the ornamental value. As a result of rating the ornamental value of trees on a five-point scale according to soil depth, it was found that the ornamental value was higher mostly in greater soil depths. *Pinus densiflora*, *Ilex serrata*, and *Nandina domestica* mostly died in 15 cm plant height, and other species also have extremely low ornamental value

Figure 4. The quality index of trees grown at three different soil depth (the higher the number of +, the better the visual quality).

A=*Thuja occidentalis*; B=*Pinus densiflora*; C=*Pinus parviflora*; D=*Ilex serrata*; E=*Nandina domestica*; F=*Syringa vulgaris*.

Table 6. The correlation between soil depth and growth performances.

Species	Spearman's rho			
	RGR-Height	RGR-Root collar diameter	dry weight	quality index
<i>Thuja occidentalis</i>	0.60**	0.25	0.13	0.87**
<i>Pinus densiflora</i>	0.71**	0.66**	0.74**	0.75**
<i>Pinus parviflora</i>	-0.24	-0.03	0.22	1.00**
<i>Ilex serrata</i>	-0.03	0.30	0.51*	0.87**
<i>Nandina domestica</i>	0.32	0.47*	0.72**	1.00**
<i>Syringa vulgaris</i>	0.21	-0.70**	0.04	1.00**

** $p < .01$, * $p < .05$.

including growth condition. By species, *Ilex serrata* generally had low visual growth condition and ornamental value in all soil depths, and thus is proved not to be desirable for container growth. *Thuja occidentalis* maintained consistent form regardless of soil depth, and high visual quality in 20 cm and 30 cm. *Syringa vulgaris* showed some dead branches and leaves in 15 cm, and high visual quality in 30 cm. *Pinus densiflora*, *Pinus parviflora*, and *Nandina domestica* showed low ornamental value in 15 cm soil depth, which suggests that they must be grown in at least 20 cm (Fig. 4).

Correlation between soil depth and growth characteristics

Soil depth may be a factor that brings difference to growth condition above ground and underground by affecting changes in growth environment, and thus this study analyzed the correlation between soil depth and growth characteristics. *Thuja occidentalis* and *Pinus parviflora* have a positive correlation in which quality index increases according to soil depth. *Pinus densiflora* has a positive correlation in which relative growth of plant height and plant root collar diameter, dry weight, and quality index increase according to soil depth. *Ilex serrata* has a positive correlation in dry weight and quality index, and *Nandina domestica* has a positive correlation in relative growth of plant root collar diameter, dry weight and quality index. On the other hand, *Syringa vulgaris* had a negative correlation between growth of plant root collar diameter and soil depth, which explains that plant root collar diameter does not grow even of soil depth increases, and that greater soil depth does not necessary serve as a benefit for plant growth (Table 6).

Conclusion

This study is to determine the appropriate soil depth for each species at the initial plantation in containers by examining plant height, plant root collar diameter, biomass, and ornamental value of plants that can be used in container gardens according to soil depth. The minimum soil depth for each species must be decided considering multiple aspects such as growth conditions like plant height and plant root collar diameter, as well as photosynthesis output and visual quality in terms of ornamental value. *Pinus densiflora*, *Pinus parviflora*, and *Nandina domestica* showed poor growth and low ornamental value in 15 cm soil depth, and thus can be planted only in containers with at least 20 cm soil depth. *Thuja occidentalis* can be grown in 15 cm and has above-average ornamental value, but is desirable to plant in 20 cm. *Syringa vulgaris* showed almost no difference according to soil depth and thus can be planted in containers with at least 15 cm soil depth, but it would be favorable to grow in at least 20 cm considering ornamental value. *Ilex serrata* can grow in at least 20 cm soil depth but has overall low ornamental value, thereby not suitable for container gardens.

Since soil depths vary according to container types, it is necessary to choose containers that maintain suitable soil depth for each tree in order to facilitate growth and maintenance. To this end, the plants must be transplanted into a bigger container according to their growth. However, since it is not easy to change the size of containers set up outdoors, the plants must be replaced to younger ones after a certain period of growth. This study has significance in that it presented trees to apply according to soil depth by determining the growth health for each species in minimum soil depth of containers at the initial stage of building container gardens. However, its limitation is that the results come from 2 years of growth. Follow-up research must continue to verify the changes in growth according to soil depth.

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