Growth Characteristics by Plug Tray Cell Size, Soil Type, and Fertilizer Concentration for Plug Seedling Production of *Veronica pusanensis* Y.N. Lee

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**ABSTRACT**

**Background and objective:** This study was conducted to establish a stable seedling production system for *Veronica pusanensis* Y.N. Lee, a plant that is endemic to the Korean Peninsula and is a critically endangered species, distributed along the coast of Busan, Korea.

**Methods:** In order to investigate the plug cell size (72, 128, 200 cells), soil type (commercial substrate, and mixed substrates with peat moss and perlite at ratios of 1:1, 3:1, and 4:1), and fertilizer concentration (Peters 0, 500, 1,000, and 2,000 mg \(\cdot\) L\(^{-1}\)) conditions, the plug tray was filled with soil and seeds were sown. The sown trays were placed in the growth chamber (25°C, 70% RH, PPFD 100 \(\mu\)mol \(\cdot\) m\(^{-2}\) \(\cdot\) s\(^{-1}\)) for three repetitions per treatment.

**Results:** There was no difference in the growth of seedlings according to plug cell size. Therefore, it appears to be economically superior to produce seedlings in a 200-cell plug tray. In soil type, the seedling growth increased as the ratio of peat increased, but leaf chlorosis occurred from the 7th week after sowing. Examining the growth of seedlings based on fertilizer concentration, the greatest increase in growth was found to have occurred in the 1,000 mg \(\cdot\) L\(^{-1}\) treatment.

**Conclusion:** Therefore, for the production of *V. pusanensis* seedlings, it was noted that when mixed soil with peatmoss and perlite at a ratio of 4:1 is filled in 200-cell plug trays, and the seedlings are fertilized with Peters 1,000 mg \(\cdot\) L\(^{-1}\) once a week, growth will increase the most, demonstrating excellent cost-effectiveness. However, to mass-produce high-quality seedlings in a short period, it will be necessary to use a plug tray smaller than 200 cells or to conduct various fertilization composition studies.

**Keywords:** commercial substrate, peat moss, perlite, Peters, plug tray

**Introduction**

To utilize native plants in various fields and offer new options to the ornamental plant market, research on their physiological and morphological characteristics is required. In addition, methods for propagation, seedling production, cultivation, and management of such plants should be established, and they should be able to be easily cultivated in farms, enabling large-scale production of their standardized seedlings and enhancing consumer utilization (Lee et al., 2015). Plug seedling production is the year-round planned production of healthy and standardized seedlings in systematic production facilities (Jeong et al., 2016). Processed seedlings, also called plug seedlings, are seedlings grown in uniform individual cells filled with a small amount of cohesive medium, or in soil plugs; these were introduced to South Korea in the 1990s (Park et al., 2011; Jeong et al., 2016). Plug seedlings are easy to produce and
manage, and they enable the use of automatic seeders and facilitate seedling transplantation (Fukushima et al., 2014). In addition, this production method is used for the mass production of seedlings because seeds can be saved during sowing. Further, the growth rate of seedlings is fast, and the seedling quality is uniform.

*Veronica pusanensis* Y.N. Lee is a plant that is endemic to the Korean Peninsula. It is distributed only along the coast of Busan, and has been designated as critically endangered (CR) by the Korea Forest Service (Chung et al., 2017; Korea National Arboretum, 2021). Its features include a plant height of about 20 cm, a stem with white hairs, and lanceolate green leaves (Song et al., 2020). In particular, its purple flowers bloom in a raceme in August, enhancing its ornamental value. This species is the only ground cover plant in the genus *Veronica*, which is native to Korea, and it can be used for landscaping and ornamental purposes once planted in hanging pots. Recently, this plant was sold for KRW 2,500 per 8 cm pot on an online plant sales site, and its industrialization is in progress, as it can be planted for landscaping purposes in the flower beds of urban streets and apartment buildings in Busan (Xplant, 2021).

To increase the utility of *V. pusanensis* Y.N. Lee, studies on its seed germination, cutting propagation, and shade cultivation have been conducted in recent years (Song et al., 2019; Song et al., 2020; Kim et al., 2021). According to previous studies, this plant germinated more than 94.0% at treatment temperatures of 20°C and 25°C, and the average germination days were 4.6 and 4.8 days, respectively, making it a good seed-propagated species (Song et al., 2019). When the species was propagated by cuttings, the rooting rate was 71.11% and the survival rate was 100%; further, α-Naphthalene acetic acid (NAA) treatments increased the rooting rate to 100%. Based on this, it is recommended that the cutting propagation method be used to preserve the morphological characteristics of *V. pusanensis* Y.N. Lee through mutation selection, while for general mass production, it is advantageous to use the seed propagation method. However, research on seedling production of the species for the purpose of mass-producing standardized seedlings has not yet been conducted. As such, to establish a stable production system for the standardized seedlings of *V. pusanensis* Y.N. Lee, a critically endangered and endemic species in the Korean Peninsula, this study aimed to examine the growth characteristics of seedlings according to plug cell size, soil composition, and fertilizer concentration.

**Research Methods**

**Plant material**

The seeds of *Veronica pusanensis* Y.N. Lee used in this study were harvested in October 2020 in the field (37°28′45.2″N, 127°35′51.4″E) of the Useful Plant Resources Center under the Korea National Arboretum (KNA) located in Yangpyeong-gun, Gyeonggi-do. The harvested seeds were used in this experiment after being dried at room temperature for a week and stored at 4°C with impurities removed.

**Seedling growth according to plug tray size**

To investigate the growth of the seedlings based on the size of plug trays, in January 2021, horticultural substrate (Baroker, Seoul Bio, Korea) was filled into plug trays (Bomnong co., Ltd, Korea) of the following sizes: 72 cells (W 280 × L 540 × H 45 mm, 34 mL/cell), 128 cells (W 280 × L 540 × H 48 mm, 21 mL/cell), and 200 cells (W 280 × L 540 × H 42 mm, 10 mL/cell). Two seeds were sown per cell, and the plants were thinned so that one seedling per cell would grow when cotyledons came up uniformly after 2 weeks. The seeded trays were completely randomly arranged in triplicate in a plant growth chamber, which was maintained at a temperature of 25°C and a relative humidity of 70%; the experiment was conducted for 6 weeks. The growth chamber was controlled to have a light intensity of 100 μmol · m⁻² · s⁻¹ under LED white light sources (406-770 nm), with a day length of 9 h/15 h. The plants were bottom-watered with tap water twice a week.

**Seedling growth according to soil type**

To investigate the growth of the seedlings based on the size of plug trays, in January 2021, horticultural substrate (Baroker, Seoul Bio, Korea) was filled into plug trays (Bomnong co., Ltd, Korea) of the following sizes: 72 cells (W 280 × L 540 × H 45 mm, 34 mL/cell), 128 cells (W 280 × L 540 × H 48 mm, 21 mL/cell), and 200 cells (W 280 × L 540 × H 42 mm, 10 mL/cell). Two seeds were sown per cell, and the plants were thinned so that one seedling per cell would grow when cotyledons came up uniformly after 2 weeks. The seeded trays were completely randomly arranged in triplicate in a plant growth chamber, which was maintained at a temperature of 25°C and a relative humidity of 70%; the experiment was conducted for 6 weeks. The growth chamber was controlled to have a light intensity of 100 μmol · m⁻² · s⁻¹ under LED white light sources (406-770 nm), with a day length of 9 h/15 h. The plants were bottom-watered with tap water twice a week.
Lithuania) and perlite (Pl; Greenpamix, Misung, Yesan, Korea) at ratios of 1:1, 3:1, and 4:1 (v:v) (Lee et al., 2020). Two seeds were sown per cell, and when cotyledons came up uniformly after 2 weeks, the plants were thinned so that one seedling per cell would grow. The seeded trays were randomly arranged in triplicate in a plant growth chamber, and the plants were bottom-watered with tap water twice a week, and the experiment was conducted for 6 weeks. To investigate the chemical and physical properties of the soil used in the experiment, pH, electrical conductivity (EC), and moisture content were measured. For the pH and EC measurements, the soil was dried in a drying oven and was shaken and mixed with distilled water at a ratio of 1:5 (v:v) for 1 hour; then, the solution filtered from the mixture was measured using a pH meter (Seven Easy pH meter, Mettler Toledo, Switzerland) and an EC meter (EC Testr 11+, Eutech Instruments, Singapore) (Kang et al., 2007). The water holding capacity (WHC) of the soil was calculated by filling a pot with 15-20 g of naturally dried soil, saturating the soil as much as possible with distilled water for 12 hours, and measuring the weight of wet soil after draining the water for 30 minutes (Modi and Zulu, 2012).

\[ \text{WHC} \% = \frac{\text{WW} - \text{DW}}{\text{WW}} \times 100 \]

*(WW: weight of soil saturated with distilled water; DW: weight of dried soil)*

**Seedling growth according to fertilizer concentration**

To examine the growth of seedlings based on fertilizer concentration, in June 2021, bed soil in which Pt and Pl were mixed at a ratio of 4:1 (v:v) was prepared and filled in a 200-cell plug tray. Two seeds were sown per cell, and when uniform cotyledons came up after 2 weeks, the plants were thinned so that one seedling would grow per cell. The seeded trays were randomly arranged in triplicate in a plant growth chamber, and the experiment was conducted for 5 weeks. The plants were irrigated with tap water until the second week after sowing, and after 2 weeks, the plants were thinned out and irrigated according to fertilizer concentration. As for the fertilizer concentration, plants irrigated with tap water were used as a control, and plants treated with a solution obtained by diluting straight fertilizer (Peters professional, ICL Specialty Fertilizers, USA) in tap water at concentrations of 500, 1,000, and 2,000 mg · L⁻¹, respectively, were used as treatment groups. Each group was sub-irrigated once a week. The fertilizer used in this study contained 20% nitrogen, 20% phosphoric acid, 20% potassium, 0.05% magnesium, 0.0125% boron, 0.05% iron, 0.025% manganese, 0.0125% copper, 0.025% zinc, and 0.005% molybdenum.

**Survey items and statistical processing**

A growth survey was conducted based on the time when the seedlings in the plug trays grew and their leaves did not overlap; their roots were pruned in preparation for transplantation. Experiments by plug tray size and soil type were conducted 6 weeks after sowing, and experiments by fertilizer concentration were conducted 5 weeks after sowing. For survey items, plant height, plant width, leaf length, leaf width, number of nodes, number of leaves, fresh weight, dry weight, and maximum quantum yield were measured. Plant height, plant width, leaf length, and leaf width were measured for maximum length using the naked eye, and the number of leaves was counted for all developed leaves. Fresh and dry weights were measured with an electronic scale (Shimadzu Analytical Balance AUW2200, Shimadzu, Japan) by dividing the root and shoot parts of the plants. For the dry weight measurement, the specimens were dried in a dryer for 72 hours and then measured. The maximum quantum yield (Fv/Fm) was measured using a chlorophyll fluorometer (Maxi Imaging-PAM-series, Heinz Walz GmbH, Effeltrich, Germany) for 6 specimens per treatment.

\[ \text{Maximum quantum yield (Fv/Fm)} = \frac{(\text{Fm}-\text{Fo})}{\text{Fm}} \]

*(Fm: maximum fluorescence value induced by a saturating light source in dark-adapted plants; Fo: initial fluorescence value just before being illuminated with a saturating light source in dark-adapted plants.)*

The experimental results were analyzed via analysis of variance (ANOVA) using SAS 9.4 software (SAS Institute Inc., Cary, NC, USA). The statistical significance between treatment means of groups was compared using Tukey’s
HDS test \( (p \leq .05) \). Graphs were prepared using Sigma Plot 10 (Systat Software, Inc., IL, USA).

**Results and Discussion**

**Seedling growth according to plug tray size**

For seedling growth according to plug tray size, there was no significant difference according to the cell size of plug trays in general, but leaf width, node length, and dry weight were high in 200-cell plug tray (Table 1). The larger the cell size, the longer the plant height; the plant height was 0.3 cm longer in the 72-cell plug trays than in the 200-cell trays. Leaf width was the widest in the 200-cell plug trays, where the cell size was relatively small; the leaves were 0.3 cm wider in the 200-cell plug trays than in 128-cell ones. The dry weights of the root and shoot parts increased by 4.8 mg and 1.1 mg, respectively, in the 200-cell trays rather than the 128-cell ones. The node lengths in the 128-cell and 200-cell trays were 0.07 cm and 0.12 cm longer than in the 72-cell trays, respectively. On the other hand, there was no difference in plant width, leaf length, number of leaves, root length, number of nodes, and fresh weight according to plug tray cell size. When measuring the maximum quantum yield to investigate the photosynthetic efficiency, it was found that there was no difference according to plug tray cell size (Fig. 1).

It is important to select an appropriate plug tray for plants because the planting density and the amount of medium not only vary depending on the size of plug trays and the number of plug tray cells, but also affect the growth of crops (Jang et al., 2014). In general, for experiments based on plug tray size, the growth of plants tends to in-

![Fig. 1. Quantum yield (Fv/Fm) of Veronica pusanensis Y.N.Lee seedlings under different plug tray cell size (A), soil type (B) and fertilizer concentration (C). Within-graph means followed by the same letter are not significantly different by Tukey’s honestly significant difference test at \( p \leq 0.05 \) (n =3).](image_url)

**Table 1.** Growth of *Veronica pusanensis* Y.N.Lee seedlings measured at 6 weeks after sowing as affected by plug cell size

| Plug cell size | Plant height (cm) | Plant width (cm) | Leaf length (cm) | Leaf width (cm) | Root length (cm) | Node number | Intemode length (cm) | Fresh weight (mg) shoot | Fresh weight (mg) root | Dry weight (mg) shoot | Dry weight (mg) root |
|---------------|-------------------|------------------|------------------|-----------------|------------------|-------------|-----------------------|------------------------|------------------------|-----------------------|------------------------|
| 72            | 2.2a              | 5.5a             | 1.9a             | 1.5ab           | 8.8a             | 1.8a        | 0.21b                 | 163.0a                 | 15.0a                  | 12.7ab                | 1.4a                  |
| 128           | 2.1ab             | 5.5a             | 1.8a             | 1.3b            | 8.2a             | 1.8a        | 0.28a                 | 132.0a                 | 10.4a                  | 9.9b                  | 1.3b                  |
| 200           | 1.8b              | 5.6a             | 1.9a             | 1.6a            | 9.0a             | 1.9a        | 0.33a                 | 166.5a                 | 23.9a                  | 14.7a                 | 2.4a                  |

Significance: **NS NS NS NS NS NS NS NS NS NS NS NS **

\(^a^\)The different letters are significantly different \( (p \leq .05) \) using Tukey’s HSD test \( n = 3 \).\n
\(^NS NS^\) Non-significant or significant at \( p < .01 \), respectively.
crease as the plug tray cell size increases. This is because, as the size of the plug tray increases, both the amount of bed soil in the cell and the nutrients in the soil also increase, which further promotes plant growth (Yeoung et al., 2005). A study of Veronica rotunda var. subintegra (Nakai) T. Yamaz. also reported that the seedling growth increased as the plug tray size increased. It was judged that the larger the container capacity during seedling cultivation, the better the environment of the root part; the growth of the shoot part was then promoted based on the increase in the T/R ratio (Lee et al., 2020). However, in this study, there was no significant difference noted based on plug tray size, though leaf width, node length and dry weight increased (rather than decreased) in the 200-cell plug trays. Particularly, in the 200-cell plug trays, the dry weight increased the most and the roots were better formed than in the other treatment groups, so the growth of the shoot part might increase as much as in other treatment groups. The smaller the plug tray cell size, the smaller the volume of the medium that can be filled; therefore, the loss of water, which contains nutrients, occurs quickly due to gravity in the medium or environmental factors (Kim et al., 2018). It seems that the smaller the cell size, the faster the water loss, which leads to slight water stress in the seedlings and stimulates the growth of new roots; it can also cause the roots to quickly reach the wall and bottom of the cell, promoting the development of new roots (Kostopoulou et al., 2010). In addition, Kim et al. (2019) reported that the smaller the plug tray cell size, the earlier root pruning for transplantation, and planting occurred, which were also found to be effective for seedling growth after transplantation and required less labor in the transplantation process. For this reason, when selecting a plug tray for V. pusanensis Y.N. Lee, a plug tray with relatively small cells is recommended from an economic perspective, particularly if there is no significant difference in growth depending on plug tray cell size.

### Seedling growth according to soil type

By measuring the pH, EC, and WHC by soil type used in this study, it was found that the pH of the horticultural substrate was the lowest at 5.1, but the EC was the highest at 0.96 dS · m⁻¹ (Table 2). On the other hand, the pH of PI medium was 6.91, which was close to neutral, the EC was 0.02 dS · m⁻¹, and the WHC was lowest at 64.70%. The pH of Pt medium, and mixtures of Pt and PI were similar, and the EC and WHC were higher as the Pt content increased. In particular, the pH and EC levels between the group treated only with Pt and the group treated with mixtures of Pt and PI at a ratio of 4:1 were similar, but the WHC was higher in the group treated only with Pt. When examining soil type, the seedling growth was found to increase in the medium mixed with Pt and PI at a ratio of 4:1 (Table 3). For the group treated with mixed substrate with Pt and PI at a ratio of 4:1, the plant width was the widest at 5.8 cm, the leaf growth was the best with a leaf length of 2.2 cm and a leaf width of 1.7 cm, and the number of nodes was also the highest. The root length increased by 1.6-2.6 cm in the groups treated with bed soil mixed with Pt and PI compared to those treated only with horticultural substrate, and the node length also increased by 0.2-0.3 cm. The fresh weight of the shoot part increased in the group treated with mixed substrate with Pt and PI at a ratio of 4:1, and the dry weight increased in both groups treated with mixed substrates with Pt and PI at a ratio of 3:1 and 4:1. The dry weight of the root part increased by 1.7 mg in the group treated with mixed substrate of Pt and PI at a ratio of 3:1 than in that treated only with horticultural substrate. On the other hand, there was no difference in the plant height and fresh weight of the root part by treat-

| Soil type | pH  | EC   | Water holding capacity (%) |
|-----------|-----|------|---------------------------|
| Cs²       | 5.11 c² | 0.96 a | 81.80 ab                  |
| Pt        | 6.05 b | 0.29 b | 83.66 a                   |
| PI        | 6.91 a | 0.02 d | 64.70 d                   |
| Pt:Pl = 1:1 | 6.24 b | 0.14 c | 76.63 c                   |
| Pt:Pl = 3:1 | 6.27 b | 0.24 bc | 78.73 bc                  |
| Pt:Pl = 4:1 | 6.30 b | 0.26 b | 80.33 b                   |

Significance *** *** ***

*²Cs, commercial substrate; Pt, peatmoss; PI, perlite.
³The different letters are significantly different (p ≤ .05) using Tukey's HSD test (n = 3).
⁴Significant at p < .001.
ment group. The maximum quantum yield was the highest at 0.6458 in those treated only with the horticultural substrate (Fig. 1).

Seedling production using the basic materials that constitute bed soil enables us to obtain high-quality plants in a short period of time at a low cost (Cunha et al., 2006). In horticultural substrates currently sold in South Korea, organic substances including Pt, and inorganic substances including Pl, vermiculite, and rockwool, which have a great effect on plant growth, are mixed (Kwon et al. 2016; Lee et al. 2020). In particular, when Pt, an organic medium, and Pl, an inorganic medium, are mixed, air permeability and WHC are supplemented, and pH and EC are stabilized (Wilson, 1986). In this study, it was also found that the seedlings grew well in the bed soil mixed with Pt and Pl.

In addition, as the ratio of Pt increased, the growth of V. pusanensis Y.N. Lee also increased, indicating that Pt, an inorganic material, had a positive effect on the growth of seedlings. Dendranthema grandiflorum 'Baekma' increased in plant height and in the fresh weight of the shoot part when grown in bed soil mixed with Pt and Pl at a 3:1 ratio. For Zantedeschia spp. 'Florex Gold', the growth of small microtubers was increased in the treatment where an appropriate amount of Pl was added to Pt. (Yoo, 2008; Yoo and Roh, 2012). For Freesia hybrid 'Gold Rich', it was noted that when Pt was mixed in the bed soil, the plant height, number of leaves, and fresh weight increased, while Gerbera jamesonii Blous 'Sunny Lemon' showed better flower quality as the ratio of Pt increased (Lee, 2017; Kil et al., 2011). In this study, there was no significant difference in the WHC between the group treated with mixed substrate with Pt and Pl at a ratio of 4:1 and that treated only with the horticultural substrate. In general, the WHC of large-grained Pl was 20% (Kwon et al., 2021), but in this study using small-grained Pl, the WHC was 64.70%. Among bed soil mixtures, the WHC of the group treated with bed soil with Pt and Pl at a ratio of 4:1, which had high Pt content, was 80.33%, similar to that treated only with horticultural substrate. On the other hand, flower plants actively grow in an acidulous or alkalescent medium, and the pH of the commercial substrate ranges from about 5-6 (Rhie et al., 2018).

In this study, the horticultural substrate had a pH of 5.11 and the Pt and Pl mixed media had a pH of 6.24-6.30. The growth of the seedlings of V. pusanensis Y.N. Lee was active in the Pt and Pl mixed media which were closer to alkalescent than the horticultural substrate. In addition, the horticultural substrate contained fertilizer components including nitrate nitrogen, ammonia nitrogen, and available phosphoric acid, and the EC was the highest at 0.96 ds m⁻¹, which was expected to be better for seedling growth. However, the seedlings grew better in the Pt and Pl mixed media with relatively low EC. On the other hand, the maximum quantum yield of the mixed media was also lower than that of the horticultural substrate, so the leaves of the seedlings began to turn yellow in the Pt and Pl mixed media starting from the 7th week after sowing, suggesting that the plant was under in vivo stress conditions. Therefore, when cultivating V. pusanensis Y.N. Lee seedlings in Pt and Pl mixed media, the recommendation is to cultivate

### Table 3. Growth of Veronica pusanensis Y.N. Lee seedlings measured at 6 weeks sowing as affected by the soil type

| Soil type | Plant height (cm) | Plant width (cm) | Leaf length (cm) | Leaf width (cm) | Root length (cm) | Root width (cm) | Node number | Internode length (cm) | Fresh weight (mg) | Dry weight (mg) |
|-----------|------------------|------------------|------------------|------------------|------------------|------------------|--------------|----------------------|-----------------|---------------|
| Cs        | 1.8a             | 5.4ab            | 2.0ab            | 1.5b             | 7.6a             | 7.9b             | 1.7b         | 0.3b                 | 178.2ab         | 43.0a         |
| 1:1       | 1.8a             | 4.8c             | 1.7c             | 1.4b             | 7.0a             | 10.5a            | 1.8b         | 0.5a                 | 126.7b          | 30.9a         |
| Pt:Pl     | 3:1              | 1.8a             | 5.1bc            | 1.9bc            | 7.4a             | 10.3a            | 1.9ab        | 0.5a                 | 165.2b          | 44.3a         |
| Pt:Pl     | 4:1              | 2.1a             | 5.8a             | 2.2a             | 1.7a             | 7.4a             | 9.5ab        | 2.2a                 | 227.4a          | 47.3a         |

Significance: NS, *, ***, Non-significant or significant at $p \leq .05$, or .001, respectively.

*Cs, commercial substrate; Pt, peatmoss; Pl, perlite.

The different letters are significantly different ($p \leq .05$) using Tukey's HSD test ($n = 3$).
them for less than 6 weeks. Additional research should be conducted to determine the cause of leaf chlorosis.

**Seedling growth according to fertilizer concentration**

By measuring pH and EC according to fertilizer concentration, it was found that the pH for fertilizer concentrations of 0, 500, 1,000, and 2,000 mg · L⁻¹ was 6.3, 6.5, 6.4, and 6.2, respectively, while the EC was 0.17, 0.48, 0.89, and 1.60 dS · m⁻¹, respectively. When examining seedling growth based on fertilizer concentration, the fertilized groups grew better than the unfertilized group (Table 4). For the group fertilized at a concentration of 1,000 mg · L⁻¹, the plant height was 3.1 cm, which was 1.3 cm longer than that of the unfertilized group. Further, the plant width was 6.8-7.7 cm, which was 1.3-2.2 cm longer than that of the unfertilized group. The leaf length was the longest for the treatment group with a concentration of 1,000 mg · L⁻¹ or more, and the leaf width was widest for the group treated at a concentration of 2,000 mg · L⁻¹. On the other hand, the root length increased as the fertilizer concentration decreased, and it was 1.7 cm longer in the untreated group than in the group treated at a concentration of 2,000 mg · L⁻¹. The fresh weight of the shoot part increased by 1.8-2.2 times in all treatment groups when compared with the untreated group, while that of the root part increased the most, up to 72.6 mg, in the treatment group with a concentration of 500 mg · L⁻¹. The dry weight of the shoot parts also increased more in the fertilized groups than in the unfertilized group. The dry weight of the root parts was 4.3 and 4.6 mg in the treatment groups at concentrations of 500 and 1,000 mg · L⁻¹, respectively, while it decreased to 3.0 mg in the group treated with a concentration of 2,000 mg · L⁻¹. There was no difference in the maximum quantum yield between treatment groups.

Fertilizers not only provide nutrients to plants, but also improve the physical environment of the soil that affects plant growth. However, excessive fertilization increases the salinity concentration in the soil, which inhibits root growth and lowers the osmotic potential of cells to delay growth. As the salinity concentration becomes more severe, the roots become brown and wither to death (Kim et al., 2015). In addition, when the EC level of the nutrient solution is increased, the osmotic potential of plant roots is lowered; thus, the water absorption of crops is reduced (Jeong et al., 2020). During the cultivation of *V. pusanensis* seedlings, the root length, and fresh and dry weights of the root part decreased in the treatment group with a concentration of 2,000 mg · L⁻¹. This indicates that the roots did not actively grow due to an accumulation of salts in the soil, which resulted from the high-concentration fertilization and the reduced amount of water absorption in the plants. Even when cultivating *Hepatica asiatica* Nakai, there was no significant difference between treatment groups across the growth indicators, including fresh weight, plant height, and leaf number; however, the plants weakened in the high concentration treatment group and many plants gradually withered and died (Jeong et al., 2015). On the other hand, when growing potted *Orostachys* (*Nungyu bawisol* in Korean), the higher the concentration of liquid

| Fertilizer concentration (mg · L⁻¹) | Plant height (cm) | Plant width (cm) | Leaf length (cm) | Leaf width (cm) | Leaf number | Root length (cm) | Node number | Internode length (cm) | Fresh weight (mg) shoot | Fresh weight (mg) root | Dry weight (mg) shoot | Dry weight (mg) root |
|-----------------------------------|------------------|------------------|------------------|------------------|--------------|------------------|--------------|----------------------|------------------------|----------------------|-----------------------|----------------------|
| 0                                 | 1.8c             | 5.5b             | 2.0c             | 1.7c             | 7.6a         | 9.7a             | 2.0a         | 0.5a                 | 194.8b                 | 50.8ab               | 18.7b                 | 4.0ab                |
| 500                               | 2.1c             | 6.8a             | 2.5b             | 2.1b             | 8.2a         | 9.0ab            | 1.9a         | 0.9a                 | 342.3a                 | 72.6a                | 28.9a                 | 4.3a                 |
| 1,000                             | 3.1a             | 7.7a             | 2.8a             | 2.3ab            | 8.4a         | 8.7ab            | 2.4a         | 0.8a                 | 432.4a                 | 60.7ab               | 33.8a                 | 4.6a                 |
| 2,000                             | 2.7b             | 7.4a             | 2.7a             | 2.4a             | 8.3a         | 8.0b             | 2.2a         | 0.7a                 | 400.8a                 | 41.0b                | 29.9a                 | 3.0b                 |

*The different letters are significantly different (p ≤ .05) using Tukey's HSD test (n = 3).
NS, *,**, *** Non-significant or significant at p < .05, .01, or .001, respectively.
fertilizer and the greater the number of treatments, the more
the growth was promoted. When cultivating seedlings of
Thalictrum rochebruneanum Franch. & Sav. and T. uchiya-
mae Nakai, seedling growth increased following fertiliza-
tion with Hyponex 1,000 times once a week (Chon et al.,
2011; Lee et al., 2015). As such, the fertilization require-
ment varies depending on the plant species or growth stage, so
it is important to find a fertilization treatment suitable for
the growth of each plant. The growth of the root parts in
the group treated at a concentration of 500 mg · L⁻¹ was
not different from that of the group treated at a concen-
tration of 1,000 mg · L⁻¹. However, the growth of the shoot
parts was further increased in the latter group. This in-
dicates that fertilizer treatment is required when cultivating
seedlings of V. pusanensis Y.N. Lee. It is judged that the
growth of seedlings can be increased when they are bot-
tom-irrigated with a straight fertilizer (N:P:K = 20:20:20)
diluted at a concentration of 1,000 mg · L⁻¹ once a week;
the period of seedling production can also be shortened from
6 weeks to 5 weeks, 1 week less, than in the untreated group.

**Conclusion**

This study was conducted to establish a stable seedling
production system for Veronica pusanensis Y.N. Lee, a
critically endangered species that is endemic to the Korean
Peninsula, by investigating the conditions of plug tray size
(72-, 128-, and 200-cell plug trays), bed soil type (commercial
substrate, and mixed substrates with Pt and Pl at ratios
of 1:1, 3:1, and 4:1), and fertilizer concentration (0, 500,
1,000, and 2,000 mg · L⁻¹). There was no difference in the
growth of seedlings according to the size of the plug trays,
but the production of seedlings in the 200-cell plug trays
appear to be economically advantageous (Fig. 2). In an
experiment where seedling growth was examined for each
type of bed soil, the growth of the seedlings of V. pusan-
ensis Y.N. Lee increased as the ratio of Pt with excellent
WHC increased, but leaf chlorosis occurred starting from
the 7th week after sowing. When examining seedling growth
based on fertilizer concentration, the group treated at a con-
centration of 1,000 mg · L⁻¹ demonstrated the greatest in-
crease in growth, no leaf chlorosis appeared, and the
growth period was shortened by 7 days.

Therefore, with respect to seedling production for V. pu-
sanensis Y.N. Lee, it was noted that when its seeds were
sown in 200-cell plug trays, which were filled with mixed
medium of Pt and Pl at a ratio of 4:1, and were treated
with a fertilizer (Peters) diluted at a concentration of 1,000
mg · L⁻¹ once a week, its growth increased the most and was
found to be highly economical. However, to mass produce
high-quality seedlings in a short period of time, it will be necessary to use more plug trays with cell sizes smaller than 200 cells, or to research various compositions of fertilizer solution.

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