

Growth of Grape Rootstock ('Glorie') Applying Cylindrical Paper Pot by Irrigation Method

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Abstract: This study was conducted to evaluate the effects of cylindrical paper pot (PP) size, irrigation method and irrigation frequency in 'Glorie' as a remarkable rootstock of grape in Korea. 'Glorie' was utilized into 2-, 3-, and 4-inch PPs, watering with overhead irrigation, subirrigation and their mixed method, and irrigation frequency was 1 time every four days. Evapotranspiration amount of 'Glorie' stock seedling on 30, 60, and 90 days after planting (DAPs) was investigated 4,526 g/m²/day, 5,642 g/m²/day and 6,681 g/m²/day. The dry weights of leaf and root in the 2-inch PP treatment on 90 DAPs were increased by 52.9% and 11.2%, respectively than those of control (no PP treatment). As compared to control, dry weight of leaves and root, and root length of 2-inch PP watering overhead irrigation (2PP-O) on 90 DAPs were increased 52.7%, 7.2%, and 10.8%, respectively. Compared to control, dry weight of leaves and root, and root length of 2-inch PP treatment watering four days interval with overhead irrigation method (2PP-W1) on 90 DAPs was increased by 52.7%, 7.2% and 10.8%, respectively. These results indicated that when 'Glorie' seedling applying PP was planted in 2-inch PP, and then watered every four days with overhead irrigation method, it increased the growth of grape rootstock seedling by improving growth of root and leaf.

Keywords: Cylindrical paper pot (PP), Grape rootstock, Irrigation interval, Overhead irrigation, Root growth

<https://doi.org/10.5338/KJEA.2025.44.24>

Agric. Environ. Sci. 2025, 44, 230-238

Received: June 6, 2025

Revised: June 13, 2025

Accepted: July 18, 2025

Published: August 29, 2025

Online ISSN: 2233-4173

Print ISSN: 1225-3537



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Introduction

According to agricultural statistics from the Ministry of Agriculture, Food and Rural Affairs in 2023, the domestic cultivation area of grapes (*Vitis vinifera* L.) was 14,904 ha, with a production 196,000 ton. In Korea, the main grape varieties cultivated are Campbell Early and Shine Muscat [1], and grafted seedlings using semi-dwarfing rootstocks are planted [2]. The grape rootstocks are propagated using cutting such as softwood cutting and hardwood cutting due to their good rooting ability. The grafting of grape rootstock improves resistance to biotic and abiotic stresses [3-5]. In Korea, Campbell Early rootstock is grafted manually using the tongue method, while omega-grafting is performed by machine [6]. It is known that for successful grafting of grapevines, the rooting of the rootstock or the establishment of the rootstock and scion after grafting and cutting can significantly affect the sprouting of the scion [7].

Grape propagation is affected by media, plant hormone, light, temperature and irrigation method [8]. Among the factors, propagation medium is important for the successful propagation of grape rootstock [8]. The properties of the media were determined by the optimal blending ratio of peat moss, cocopeat, perlite, and vermiculite for the growth of grape seedling [9]. Peat moss and cocopeat improve physicochemical properties of the media by increasing water holding capacity and exchangeable capacity, improved of media [10], while perlite enhances physical properties by increasing a porosity and permeability [11]. The properties of a growing medium are influenced by the substrate materials and their proportions, making an appropriate blending ratio essential for optimal rootstock growth [9]. Hydrogel, supper absorption polymer, improves shoot growth in growing media where it was used as substrate material, due to its ability to increase soil water holding capacity and soil porosity [12].

To produce healthy grape seedlings, methods such as grafting a scion onto a rootstock are employed [6], and their propagation has done by cutting [13]. Grape rootstock can be easily propagated in a horticultural substrate due to its good rooting [8]. To achieve a high rooting success rate in a cutting, a propagating medium with both high water capacity and good aeration is essential [13]. Watering plays a key role in determining seedling quality and overall production during propagation [14]. The water-holding capacity of the substrate is known to enhance the rooting rate of cuttings [15]. Hydrogels improve the growth of tomato (*Solanum lycopersicum*) seedlings by improving the physicochemical properties of the growing medium. This is due to their excellent water-holding capacity and the increase in particle volume after water absorption [16]. Hydrogels regulate water availability for planted crops by increasing the overall water-holding capacity of the growing medium. However, it is important to note that not all of this water is readily available for plant uptake [17]. As enhanced root development in cuttings affects shoot survival rates [8], promoting rooting and root growth is crucial for seedling propagation. The utilization of PP in cucumber (*Cucumis sativus* L.) seedling production enhances initial root growth [18]. The Rural Development Administration (RDA) recommends rootstocks such as 'Glorie', 'SO4', '1103 Paulsen', '5BB', and 'Kober 5BB' for Shine Muscat, a variety whose cultivation area has been increasing in recent grape cultivation. Therefore, this study investigated the growth of 'Glorie' grape seedlings propagated in paper pots (PP) filled with a growing medium composed of hydrogel (HG) and horticultural substrate, focusing on the effects of PP size and watering method on seedling development.

Results and Discussion

Evaporation of grape by growth period

The evaporation, transpiration, and evapotranspiration of the grape rootstock planting pots were investigated at each test date (Table 1). On January 1st, January 31th, and February 29th, evaporation was 3,574 g/m²/day, 3,394 g/m²/day, and 3,508 g/m²/day, respectively, transpiration 952 g/m²/day, 2,248 g/m²/day, and 3,173 g/m²/day, respectively, and evapotranspiration 4,526 g/m²/day, 5,642 g/m²/day, and 6,681 g/m²/day, respectively. Evaporation rates did not differ significantly across growth stages, likely due to stable indoor temperature and relative humidity, which resulted in consistent evaporation. Transpiration increased with each 30-day interval, likely due to increased water use as leaves developed with seedling growth (Fig. 1). Evapotranspiration

Table 1. Evapotranspiration amount of soil water in the substrate planting 'Glorie'

Date ¹⁾	Evaporation	Transpiration (g/m ² /day)	Evapotranspiration
January 1st	3,574a ²⁾	952c	4,526c
January 31th	3,394a	2,248b	5,642b
February 29th	3,508a	3,173a	6,681a

¹⁾ Evapotranspiration amount was investigated on January 1st, 31th and February 29th for four days.

²⁾ Means with same letters within a column are not significantly different by Duncan's multiple range test at $p \leq 0.05$ level.

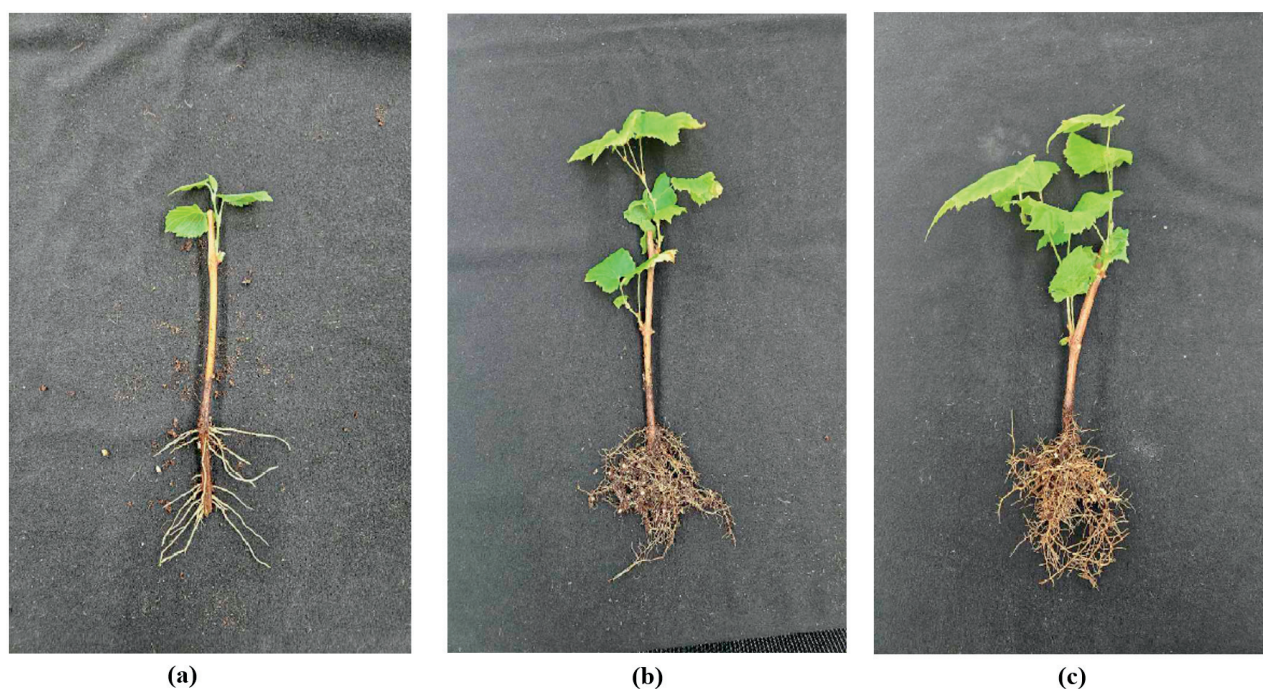


Fig. 1. Growth of 'Glorie' grown without paper pot. (a) 30 days after planting, (b) 60 days after planting, (c) 90 days after planting.

also increased with the growth period of the seedlings, suggesting that this increase was primarily influenced by the rise in transpiration rather than evaporation. Kim and Kim [19] reported that transpiration and evapotranspiration of fruit tree rootstocks increase with growth, a finding consistent with the results of the present study. The investigated evapotranspiration values for each period were set as the irrigation amounts for those respective periods.

Growth of grape rootstock in various PP's size

The impact of PP size on grape rootstock growth was evaluated (Table 2). In the January 30th investigation, the leaf width and leaf dry weight of the PP treatments were 2.87-3.48 cm and 0.32-0.53 g/plant, respectively. These values represented increases of 16.7-21.3% and 46.9-64.6%, respectively, compared to the control. Specifically, the 2PP treatment exhibited a leaf number of 5.67 ea/plant, which was a 54.5% increase over the control. For the February 29th investigation, the leaf length, leaf width, leaf dry weight, and root dry weight of the PP treatment group were 4.69-4.81 cm, 0.85-0.89 g/plant, and 1.31-1.45 g/plant, respectively, representing increases of 218.5-21.6%, 8.5-12.7%, and 25.6-39.1% compared to the control, respectively. In the March 30th investigation, the leaf dry weight and root dry weight of the PP treatment group were 1.24-1.43 g/plant and 1.76-1.95 g/plant, respectively, representing increases of 52.9-54.0% and 9.3-11.2% compared to the control, respectively. As comparing the growth of grape rootstocks during the experiment, the 2PP treatment group showed increased leaf number and growth of leaves and roots, indicating that the optimal cylindrical paper pot size for 'Glorie' growth was 2-inch (50 mm). Consequently, 2-inch paper pots were selected for use in all following experiments concerning irrigation type and interval.

As the amount of substrate, water, and nutrients scales with pot size, root development is stimulated, leading to increased seedling growth [20,21]. Compared to the control, the 2PP and 3PP treatments enhanced both shoot and root growth, indicating the importance of appropriate pot size for optimal crop seedling development [19,21,22].

Growth of grape rootstock by irrigation method in the PP

The optimal irrigation method for rootstock growth in cylindrical paper pots was investigated by comparing rootstock growth under different irrigation methods (Table 3). In the January 30th investigation, the leaf width in the PP treatments ranged from

Table 2. Growth of grape rootstock cultivated in various sizes of cylindrical paper pots

Treatments ¹⁾	Chlorophyll content	Number of leaves	Leaf length	Leaf width	Leaf dry weight	Root dry weight
	(mg/100cm ²)	(ea/plant)	(cm)		(g/plant)	
January 30th (30 DAP ²⁾)						
Control	2.72a ³⁾	3.67b	3.18a	2.87b	0.32b	0.62b
2PP	2.85a	5.67a	3.03a	3.48a	0.47a	0.81a
3PP	2.72a	3.33b	3.24a	3.34a	0.51a	0.74ab
4PP	2.68a	4.00b	3.42a	3.43a	0.53a	0.75ab
February 29th (60 DAP)						
Control	2.63a	5.33b	4.44a	3.96b	0.79b	1.04b
2PP	2.76a	7.33a	4.71a	4.69a	0.89a	1.45a
3PP	2.79a	6.33ab	4.28a	4.81a	0.86a	1.31a
4PP	2.82a	6.33ab	4.57a	4.74a	0.85a	1.36a
March 30th (90 DAP)						
Control	2.77a	7.00a	4.69a	4.64a	0.93c	1.76b
2PP	2.81a	6.00a	4.72a	4.92a	1.42a	1.95a
3PP	2.76a	7.33a	4.86a	5.09a	1.43a	1.92a
4PP	2.71a	8.00a	4.40a	4.77a	1.24b	1.76b

¹⁾ Treatments were as follows; Control [No cylindrical paper pot (PP)], 2PP (2-inch PP), 3PP (3-inch PP), and 4PP (4-inch PP). PPs planting 'Glorie' rootstock was planted into the plastic pot (5-inch pot). The plastic pots were watered every four days.

²⁾ DAP means a day after planting 'Glorie'.

³⁾ Means with same letters within a column are not significantly different by Duncan's multiple range test at $p \leq 0.05$ level.

Table 3. Growth of grape rootstock by irrigating method in the cylindrical paper pot

Treatments ¹⁾	Chlorophyll content	Number of leaves	Leaf length	Leaf width	Leaf dry weight	Root dry weight	Root length
	(mg/100cm ²)	(ea/plant)	(cm)		(g/plant)		(cm)
January 30th (30 DAP ²⁾)							
Control	2.72a ³⁾	3.67a	3.18b	2.87b	0.32b	7.62b	0.62b
2PP-O	2.85a	5.67a	3.03a	3.48a	0.47a	8.99a	0.81a
2PP-S	2.77a	3.67a	3.42a	3.59a	0.44ab	9.05a	0.68b
2PP-OS	2.83a	4.33a	3.47a	3.40a	0.46a	8.93a	0.71ab
February 29th (60 DAP)							
Control	2.63a	5.33b	4.44a	3.96b	0.79b	8.14b	1.04b
2PP-O	2.76a	7.33a	4.71a	4.69a	0.89a	9.04a	1.45a
2PP-S	2.96a	6.00a	5.09a	4.99a	0.93a	9.39a	1.47a
2PP-OS	2.77a	4.33b	5.39a	5.04a	0.90a	8.91a	1.29a
March 30th (90 DAP)							
Control	2.77a	7.00a	4.69a	4.64a	0.93b	8.84b	1.76b
2PP-O	2.81a	6.00a	4.72a	4.92a	1.42a	9.48a	1.95a
2PP-S	2.72a	8.00a	4.86a	4.73a	1.41a	9.60a	1.42c
2PP-OS	2.77a	5.67a	5.37a	4.89a	1.33ab	9.08ab	1.78b

¹⁾ Treatments were as follows; Control [No cylindrical paper pot (PP)], 2PP-O (2-inch PP applying overhead irrigation), 2PP-S (2-inch PP applying subirrigation), 2PP-OS (2-inch PP applying both overhead irrigation and subirrigation). PPs planting 'Glorie' rootstock was planted into the plastic pot (5-inch pot). The plastic pots were watered every four days.

²⁾ DAP means a day after planting 'Glorie'.

³⁾ Means with same letters within a column are not significantly different by Duncan's multiple range test at $p \leq 0.05$ level.

3.40-3.59 cm, showing an increase of 18.6-25.2% compared to the control. The leaf dry weight in the 2PP-O and 2PP-OS treatments was 0.47 g/plant and 0.46 g/plant, respectively, representing increases of 46.8% and 44.8% compared to the control. The root dry weight in the 2PP-O and 2PP-S treatments was 0.81 g/plant and 0.78 g/plant, respectively, showing increases of 30.1% and 26.3% compared to the control. In the March 30th survey, the PP treatments showed leaf dry weights ranging from 1.33-1.42 g/plant and root dry weights ranging from 1.42-1.95 g/plant. Compared to the control, leaf dry weight in the 2PP-O and 2PP-S treatments increased by 52.9% and 52.5%, respectively. Root dry weight in the 2PP-O treatment also increased by 11.2% compared to the control. These results showed that overhead irrigation for grape rootstocks in the PP improved the growth of shoot and root.

Comparison of irrigation methods in PPs showed that the 2PP-O treatment enhanced both shoot and root dry weight of grape rootstocks, indicating that overhead irrigation was the most appropriate for their early growth. Jaleta and Sulaiman [8] found that shoot development in grapes propagated by cuttings is influenced by the degree of rooting. The rooting in grape rootstock during propagation is influenced by the properties of the growing medium [23], and its water-holding capacity plays a crucial role in determining grape water use efficiency and overall plant growth [24]. While the water-holding capacity of growing media is inherently influenced by their physicochemical properties, which are determined by the combination of raw materials [8], the actual water content within the medium is primarily determined by irrigation amount [25]. In seedling production, water is supplied through overhead and subirrigation. When fertilization is involved, seedling growth is enhanced with subirrigation [26]. When seedlings were cultivated with only irrigation and no fertilization, Koa (*Acacia koa*) seedlings showed no significant difference based on the irrigation method [27], whereas apple (*Malus prunifolia*) seedlings did. This indicated variations based on crop type and seedling production method [20]. Additional research is warranted to explore how fertilization methods affect seedling growth and quality throughout different growth stages.

Growth of grape rootstock by irrigation interval in the PP

The growth of 'Glorie' rootstocks in PPs was investigated based on the irrigating interval under overhead irrigation treatment (Table 4). In the investigation on January 30th, the PP treatment showed ranges of 5.67-6.00 ea/plant for the number of leaves, 3.44-3.48 cm for leaf width, 0.45-0.47 g/plant for leaf dry weight, and 0.81-0.83 g/plant for root dry weight, respectively. Compared to control, numbers of leaves in 2PP-W1 and 2PP-W2 treatment increased by 54.5% and 63.6%, respectively, leaf width 21.3% and 20.2%, dry weight of leaf 46.9% and 41.7%, and dry weight of root 30.1% and 33.3%. In the investigation on February 29th, the PP treatment showed ranges of 7.00-7.33 ea/plant for the number of leaves, 4.69-4.94 cm for leaf width, 0.89-0.90 g/plant for leaf dry weight, and 1.45-1.61 g/plant for root dry weight, respectively. Compared to control, numbers of leaves in 2PP-W1 and 2PP-W2 treatment increased by 37.5% and 31.3%, respectively, leaf width 18.5% and 25.0%, dry weight of leaf 12.7% and 14.4%, and dry weight of root 39.1% and 55.1%. In the investigation on March 30th, the PP treatment showed ranges of 1.39-1.42 g/plant for leaf dry weight, and 1.95-1.97 g/plant for root dry weight, respectively. Compared to control, dry weight of leaves in 2PP-W1 and 2PP-W2 treatment increased by 52.9% and 49.6%, respectively, and dry weight of root 11.2% and 12.3%. These experimental results suggested that an irrigation interval of every four days improved the growth of grape rootstock in the 2PP.

The root growth of grape rootstock was improved by PP treatments, and these treatments did not significantly different to irrigation frequency. Water holding capacity and aeration in the media were enhanced to seedling growth [15]. These improvements also led to increased seedling production and enhanced seedling quality. For healthy seedling production, a proper irrigation cycle is essential. This is because irrigation not only provides plants with water but also impacts the water potential of the growing medium after application [20].

In plant growth, the irrigation cycle is determined by the amount of water absorbed by the plant from the growing medium (transpiration) and the amount lost to the atmosphere through evaporation [28]. Therefore, irrigation frequency could be determined through the investigation of evapotranspiration [20]. In this study, water loss from the growing medium was evaluated

Table 4. Growth of grape rootstock by irrigating frequency in the cylindrical paper pot

Treatments ¹⁾	Chlorophyll content (mg/100cm ²)	Number of leaves (ea/plant)	Leaf length (cm)	Leaf width (cm)	Leaf dry weight (g/plant)	Root dry weight (g/plant)	Root length (cm)
January 30th (30 DAP ²⁾)							
Control	2.72a ³⁾	3.67b	3.18a	2.87b	0.32b	7.62b	0.62b
2PP-W1	2.85a	5.67a	3.03a	3.48a	0.47a	8.99a	0.81a
2PP-W2	2.79a	6.00a	3.43a	3.44a	0.45a	8.65a	0.83a
February 29th (60 DAP)							
Control	2.63a	5.33b	4.44a	3.96b	0.79b	8.14b	1.04c
2PP-W1	2.76a	7.33a	3.71a	4.69a	0.89a	9.04a	1.45b
2PP-W2	2.63a	7.00a	5.22a	4.94a	0.90a	9.17a	1.61a
March 30th (90 DAP)							
Control	2.77a	7.00a	4.69a	4.64a	0.93b	8.84b	1.76b
2PP-W1	2.81a	6.00a	4.72a	4.93a	1.42a	9.48a	1.95a
2PP-W2	2.74a	6.33a	4.87a	4.87a	1.39a	9.91a	1.97a

¹⁾ Treatments were as follows; Control [No cylindrical paper pot (PP)], 2PP-W1 (2-inch PP applying with overhead every four days), 2CPP-W2 (2-inch CPP applying with overhead irrigation 2 times every four days).

²⁾ DAP means a day after planting 'Glorie'.

³⁾ Means with same letters within a column are not significantly different by Duncan's multiple range test at $p \leq 0.05$ level.

by measuring evapotranspiration from the rootstock (Table 1). During plant growth, evapotranspiration is known to be influenced by vegetation indices, leaf area index, and temperature [29,30]. Water loss during seedling propagation is closely related to seedling growth and the water-holding capacity of the growing medium [8]. The water-holding capacity of the growing medium is affected by its water potential, which was a main factor for plant growth and quality [31].

This study investigated water use and changes in the early growth of grapevine seedlings grown in PPs. The results indicated that the growth of grapevine cuttings was superior when irrigation was applied twice a week as overhead irrigation in 2-inch PPs. Considering the water potential of the growing medium and the stage-specific water use of the rootstock, additional research and data collection regarding the amount, frequency, and method of water supply were necessary to optimize the scientific irrigation of fruit tree seedlings. Furthermore, additional research on factors such as fertilization amount and method at different seedling growth stages was required to develop a comprehensive potted seedling production system for the production of standard quality grape seedlings.

Materials and Methods

Materials

From January to April 2024, this study was conducted over approximately three months at the Tissue Culture Laboratory of Daegu University. Grape (*V. vinifera* L.) was used as the test crop, and 'Glorie' (one-year-old seedling), a variety used as rootstock, was obtained from a seedling company and used in the study. Commercial horticultural growing media (CHM; Shinsung Mineral Co. Ltd., Seongnam, Korea) and hydrogel (HG; Terragreen Co. Ltd., Hwaseoung, Korea), provided by companies A and B respectively, were the tested substrates, and there used their mixture. To achieve a homogeneous mixture of CHM and HG (CHM+HG), the HG was hydrated with tap water prior to mixing, with the hydrated HG comprising at least 4% of the final blend. The acidity, electrical conductivity, and bulk density of CHM+HG were pH 6.37, 0.71 dS/m, and 0.38 g/cm³, respectively. A material similar to that of PPs donated by farmers was purchased and utilized. The experiment took place in

the Plant Tissue Culture Laboratory at Daegu University, where the temperature was maintained at 25°C, the relative humidity at 70%, and the light intensity at 65 $\mu\text{mol}/\text{m}^2/\text{sec}$.

Growth of grape rootstock in various PP's size

Considering common seedling pot sizes, the PPs were made in 2-inch, 3-inch, and 4-inch sizes. Grape vine's rootstocks were planted in the PPs after filling them with horticultural soil, taking into account the soil's bulk density. After planting in the cylindrical paper pots, the seedlings were transplanted into 5-inch plastic pots (12.7 cm diameter, 13 cm depth). The plastic pots were filled with the test soil. After saturating the pots with water and weighing them, we measured the daily evapotranspiration of the grape rootstocks on January 25th and August 25th. Based on these measurements, we determined the appropriate irrigation amount. Daily irrigation was administered using a double-head method, a common practice in seedling management. Evaporation was measured from pots filled with the horticultural substrate but without grape rootstocks, and evapotranspiration was investigated in pots with grape rootstocks. The horticultural substrate in the pots was saturated with tap water, and then allowing excess water to drain by gravity for 2 hours. The weight of each pot was measured every 24 hours using a balance (ARB 120, OHAUS, NJ, USA). The pot weight was measured until the pot weight reached a constant value after water was supplied on January 1st, and until temporary wilting was observed on January 30th and February 29th. Across all experimental periods, the pots reached a constant weight and temporary wilting occurred after approximately 96 hours.

Growth of grape rootstock by irrigation method in the PP

Cylindrical paper pots were manufactured in 2- and 3-inch sizes, taking into account the dimensions of standard seedling pots. After considering the bulk density of the tested growing media, weighed horticultural substrate was used to fill the prepared cylindrical paper pots, and then grape rootstocks were planted. We investigated the daily evapotranspiration of grape rootstocks at different times (January 1st, January 30th, and February 29th) and then applied the appropriate irrigation amounts. For overhead irrigation, we watered the surface of each pot. Subirrigation involved delivering water through the bottom of the pots. With the combined method, we supplied 50% of the daily evapotranspiration via overhead irrigation and the remaining 50% via subirrigation, with irrigation occurring every four days.

Growth of grape rootstock by irrigation interval in the PP

Based on standard seedling pot dimensions, cylindrical paper pots were produced in 2- and 3-inch sizes. The pots were then filled with a weighed amount of horticultural substrate, calculated based on the volume of the pots and the bulk density of the tested growing media. Following planting of the grape rootstocks, daily evapotranspiration was assessed on January 1st, January 30th, and February 29th to establish weekly irrigation regimes. Using overhead irrigation, the determined weekly irrigation was applied either as a single application every four days or split into two 50% applications, also administered every four days.

Growth investigation of grape rootstock grown in PP

The grape rootstocks were evaluated on three occasions (January 1st, January 30th, and February 29th), with measurements taken every 30 days following planting. Seedling development was determined by assessing chlorophyll content, leaf length, leaf width, leaf dry weight, and root dry weight. Leaf chlorophyll content was assessed with a chlorophyll meter (SPAD-501 plus, Minolta, Tokyo, Japan), with the final chlorophyll content calculated using the manufacturer's specified equation. Leaf length and width were measured using a ruler to determine the length and width of the leaves. To investigate the growth of the rootstocks' shoot and root parts, the dry weights of the leaves and roots were measured, respectively.

Statistical analysis

Statistical analysis was performed using SPSS (ver. 27.0, IBM, NY, USA), and Duncan's multiple range test was used to determine significant differences between treatment means.

Data Availability: All data are available in the main text or in the Supplementary Information.

Author Contributions: Y.-S. Kim conceived and designed the research, wrote the first manuscript, and revised the manuscript, provide critical feedback; W.-S. Kim led the growth experiment, collected the data, and performed the statistical analysis.

Notes: The authors declare no conflict of interest.

Additional Information:

Supplementary information The online version contains supplementary material available at <https://doi.org/10.5338/KJEA.2025.44.24>

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Peer review information Korean Journal of Environmental Agriculture thanks the anonymous reviewers for their contribution to the peer review of this work.

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