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Effects of different irrigation rates on the yield and quality of greenhouse-cultivated *Platycodon grandiflorus* crops considering transpiration

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Abstract: The consumption of agricultural water resources is enormous, and in the face of water scarcity, optimizing the utilization rate of water resources is an urgent need. As a common medicinal plant, the planting area of *Platycodon grandiflorus* crops has increased. Therefore, in order to maximize the yield and quality of *Platycodon* crops, different irrigation treatment methods are developed in this study based on their evaporation capacity and the impact of different irrigation amounts on *Platycodon* crops is explored. Different irrigation amounts affect various indicators of *Platycodon* plants. The experimental results of this study indicate that for the daily transpiration of *Platycodon*, 120% irrigation is more effective during the maturity period, and the stemflow efficiency performs better overall on sunny days. Irrigation at a rate of 120% can obtain the maximum number of leaves. Regarding the quality of *Platycodon grandiflorus* crops, 120% irrigation can achieve the highest contents of saponins, flavonoids, and polysaccharides, but 100% irrigation is required to achieve the highest soluble protein contents. Overall, *Platycodon* crops require 100% irrigation during the flowering stage and 120% irrigation during the maturity stage. As the temperature increases, the irrigation amount should be appropriately increased, and it should be reduced as the temperature decreases. This research demonstrates the impact of irrigation volume on *Platycodon* crops, and controlling the irrigation volume can effectively enhance the utilization efficiency of water resources.

Key words: *Platycodon grandiflorus*, transpiration, irrigation volume, yield, quality

1. Introduction

Agriculture, as the world's largest industry in terms of freshwater use, has a wide range of subfields entailing the cultivation of crops and livestock farming (Arora et al., 2022). Freshwater is one of the essential resources for agriculture. In agricultural production, freshwater is used to irrigate farmland, providing water and nutrients for plants (Jeet et al., 2022). A large amount of fresh water is used for irrigation in farmland to meet the growth needs of crops. In addition, providing drinking water for animals and cleaning and disinfecting farms also requires the use of freshwater resources (Qu et al., 2022). According to data from the Food and Agriculture Organization of the United Nations, approximately 70% of global freshwater is used for agriculture (Millard et al., 2020). This demonstrates the dependence of agriculture on freshwater resources and the importance of these resources. Water resource management in agriculture is crucial for ensuring food safety, the sustainable use of water resources, and environmental protection. In order to ensure the sustainable development of water resources, effective utilization and management methods of water resources must be considered, and scientific and reasonable systems need to be developed for crop irrigation. In the field of agriculture, especially irrigated agriculture, scientific and reasonable irrigation systems are crucial for ensuring the growth and development of crops and the efficient utilization of water resources (Deng et al., 2020). Such irrigation systems can help farmers reduce water waste while ensuring that crops receive appropriate water supplies. Currently, for conventional crops, transpiration is the main driving force behind their water and fertilizer transportation channels, and transpiration is also a major component of crop water consumption (Zhao et al., 2020). In recent years, research on the effects of transpiration and irrigation on the yield and quality of different crops has become a topic of considerable interest. As an important agricultural crop, the attention paid to *Platycodon* plants is also increasing. By scientifically and reasonably regulating irrigation amounts for *Platycodon grandiflorus* crops, water use efficiency can be optimized, water waste can be reduced, and crop yield and quality can be improved.

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A reasonable irrigation system can ensure the healthy development of crop roots, provide an appropriate water supply, and avoid excessive or insufficient soil moisture. In greenhouse-cultivated crops such as *Platycodon grandiflorus*, the water consumed by transpiration has a significant impact on the growth and yield of crops. In order to rationalize crop irrigation and enhance the water and fertilizer utilization efficiency of crops, the effects of different irrigation amounts based on transpiration on the yield and quality of *Platycodon grandiflorus* in greenhouse cultivation were explored in the present study. The innovation in this research lies in the study of the yield and quality of *Platycodon* crops based on transpiration. The study is divided into four further sections. In the next section, the relevant literature to date is summarized. In Section 3, the materials and experimental methods used in the study are introduced. In Section 4, the experimental results of the study are presented. In the final section, the study is concluded.

2. Related works

The use of water, as an essential resource in agriculture, faces many challenges. According to current trends, with population growth and more affluent dietary habits, the demand for water in agriculture will continue to increase. This may lead to an increase in large-scale water consumption in irrigation, further exacerbating the shortage of water resources. Eckardt et al. (2023) proposed crop improvement goals for agriculture in response to the increasingly severe climate disasters in recent years. Improving crops with stronger stress resistance is of great significance, and they discussed research results in related fields and proposed suggestions for possible future situations. Mazzia et al. (2020) proposed an agricultural efficiency management improvement plan based on unmanned aerial vehicles (UAVs) to improve water resource utilization in irrigated agriculture. By combining transpiration efficiency and soil water content with the benefits of UAVs, the water resource utilization rate in traditional irrigated agriculture was effectively improved. The experimental results proved the effectiveness of this method, providing supporting data for the design of a next-generation agricultural drone guidance platform. Khan et al. (2021) used the United States as an example to study the energy flow in agriculture and found that there was a very close linkage between energy, water, and agricultural resources. They proposed two new indicators, the connectivity index and the connectivity propagation index, and explored their future evolution through a global change analysis model. The research results showed that high connectivity in resources was driven by water resources, which further proved the importance of water resources in resource circulation. Vishnoi et al. (2021) discussed the impact of increasingly frequent abnormal weather on agriculture and further studied the field of risk control in agriculture. Through research on the evolution of crop insurance, it was found that agriculture urgently needed a high-resolution weather risk prediction model. Their study demonstrated the risk factors of weather for agriculture and highlighted the positive aspects of weather-based agricultural risk control. Helal et al. (2021) proposed an agricultural quality control model based on statistical data to address the continuous upgrading of water resources in agriculture. Through the investigation of water resources, further management plans were predicted. Their experimental results proved the effectiveness of this method and they further adapted it to develop effective agricultural management policies, which can help improve water resource utilization in agricultural management. Echchelh et al. (2021) proposed a sustainable strategy for produced water (PW) irrigation in oilfields using blending and desalination techniques. The results showed that in tropical and ultraarid climates, specific mixing ratios and irrigation volumes can maintain soil stability and crop yields, and although the cost was higher than that of PW disposal, this approach was competitive in sustainable PW management, taking into account crop value. Irik et al. (2022) proposed a method to estimate the yield and quality of pumpkin seed crops under drought conditions using remote sensing technology. Their research results showed that 9 different vegetation indices were significantly correlated with seed yield, leaf area index, leaf water potential, oil, protein, and chlorophyll content, which could effectively provide data support for irrigation scheduling.

Facility-based horticultural cultivation is a technique of plant cultivation applied in a controlled environment. It utilizes greenhouses or other shading structures to create suitable growth conditions to provide the necessary temperature, humidity, light, and gas composition for plants. This cultivation method can help farmers extend the planting season, optimize the production environment, and improve the yield and quality of crops. Lowe et al. (2021) proposed a canopy density prediction solution using 3-dimensional simultaneous localization and mapping to address the issue of vineyard planting density. Their experimental results demonstrated the effectiveness of the method, with a modeling repeatability of only 3.8%, providing technical support for improving planting density. Nemacheck et al. (2023) investigated the response of wheat varieties to the biological infestation of Hessian flies in traditional wheat cultivation. For their experiments, 10 varieties with resistance greater than 70% were selected, and further experiments were conducted to select 3 varieties that maintained 100% resistance in high-temperature environments. Their study provided strong theoretical and data supporting the breeding program of wheat varieties. Van Asselt et al. (2021) evaluated the existing disinfection methods and redesigned irrigation water disinfection equipment to address the issue of leaf vegetables being susceptible to pathogen infection during irrigation. Their experimental results demonstrated the effectiveness of the combined disinfection method. Cass et al. (2020) established a database of various arthropod pests based on comprehensive management guidelines for horticultural pests in order to address the challenges faced by citrus cultivation in California. Their study found that pest density was about 10-40 times that of a sweet orange and provided supportive data for the establishment of a new pest control system for citrus cultivation in California. Harris et al. (2020) conducted a study on the use of biodegradable containers in the horticultural planting industry. Based on data from the US state of Georgia, they investigated the use of biodegradable containers by local horticulturists. Their data revealed a lack of promotion of biodegradable containers in the area.

Considering the increasing number of *Platycodon grandiflorus* plantations and the current shortage of water resources, the study of plant irrigation strategies based on plant transpiration is of great significance. This study explores the impact of different irrigation amounts considering transpiration on the yield and quality of greenhouse-cultivated *Platycodon* crops. Through this study, water resources can be reasonably utilized, excessive irrigation and waste can be avoided, and the production efficiency and quality of crops can be improved. By accurately estimating the water demands of plants and adopting scientific and reasonable irrigation strategies, the growth needs of plants can be maximized, reducing the negative effects caused by water scarcity or excess.

3. Materials and methods

This study explored the impact of different irrigation amounts on the yield and quality of greenhouse-cultivated *Platycodon grandiflorus* crops. Based on the crucial transpiration of plants, different irrigation schemes were developed to optimize water use efficiency and improve crop production performance. Several different irrigation treatment combinations were studied and designed, including normal flow irrigation, moderate reduction irrigation, and restricted irrigation. The effectiveness and differences of various irrigation schemes were evaluated by monitoring indicators such as daily plant transpiration, greenhouse environmental factors, plant parameters, and photosynthetic characteristics.

3.1. Research contents

Plants play important roles in the water cycle and occupy a significant proportion of it (Wu et al., 2023). Plants absorb water from the soil through transpiration and transport it from their roots to their leaves and other organs. The transpiration of plants is crucial for regulating precipitation distribution, affecting surface temperature and humidity, and maintaining the balance of the global water cycle. Large amounts of transpiration can increase the water vapor content in the atmosphere, thereby increasing the potential for precipitation. In addition, the water vapor released by plants through transpiration can lower the temperature of the surrounding environment, playing a role in regulating the climate and improving the local geothermal environment. Most water is guided by plants and recycled through absorption, transportation, and transpiration, ultimately returning to the soil and groundwater systems. A schematic diagram of plant transpiration is shown in Figure 1.

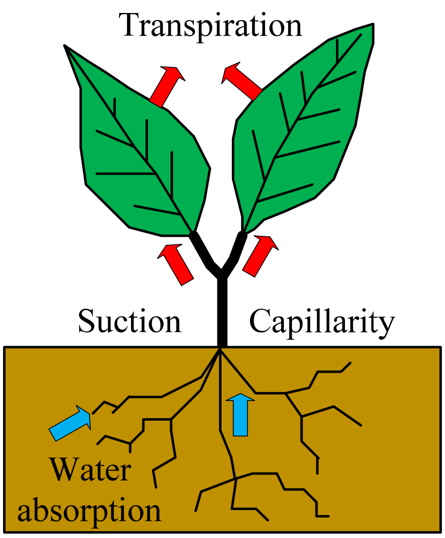

Figure 1. Schematic diagram of plant transpiration.

This study was based on the correlation between plant transpiration and evaporation and the growth of greenhouse-cultivated crops. Considering the transpiration and evaporation of plants as the basis for irrigation, the Chinese medicinal herb *Platycodon grandiflorus* was selected as the test material for irrigation treatment throughout the entire growth period of the crop. A study was conducted based on the transpiration and evaporation of these plants. Different irrigation schemes were developed based on actual transpiration and evaporation, and other factors were controlled to avoid external effects on the experimental results, reduce unforeseeable errors, and maximize the credibility of the experimental results. This study explored the interactions between plant stemflow and the environment and comprehensively considered the effects of various factors on crop yield and quality. It also explored their effects on factors such as photosynthesis and nutrient accumulation, providing support for the further optimization of irrigation schemes for greenhouse *Platycodon grandiflorus* crops and promoting the intelligent development of these crops in greenhouses.

3.2. Materials and experimental methods

This study was conducted in a wild vegetable greenhouse in an experimental field from May 2022 to September 2022. The seeds that were used were harvested in a greenhouse in 2021. A large-span asymmetric greenhouse was used in the study, with width of 20 m and ridge height of 5 m, oriented in an east–west direction. The interior of the greenhouse can maintain a relatively consistent and stable temperature, humidity, and lighting conditions to provide the most suitable environment for the growth of wild vegetables. In order to maintain consistency and comparability, the study also utilized a consistent fertilization method. This means that all *Platycodon* crops received the same type and amount of fertilization to eliminate the impact of fertilization differences on the results. By conducting this study in a greenhouse, environmental conditions could be better controlled to study the growth and development of different wild vegetable resources under relatively constant conditions. This helps in efforts to comprehensively understand the impact of greenhouse conditions on the growth of *Platycodon grandiflorus* crops, including growth speed, yield, plant appearance, and quality. These research results are of great significance for optimizing the production of *Platycodon grandiflorus*, improving crop quality, and addressing issues such as food security and agricultural sustainability (Fasusi and Babalola, 2021). The experimental analysis framework used in the overall study is shown in Figure 2.

In this study, the soil of the planting area was evaluated before sowing, with a detection depth of 0–30 cm. Organic fertilizer was applied as a base fertilizer in one session. Before emergence, the spacing between rows was 20 cm and the spacing within rows was 6 cm. In the experiment, three irrigation treatments were applied based on the irrigation amount of crops, with W1 entailing 80% daily transpiration and evaporation per plant, W2 entailing 100% daily transpiration and evaporation per plant, and W3 entailing 120% daily transpiration and evaporation per plant. The specific values of these irrigation amounts were detected and recorded using crop water consumption recorders. Table 1 provides the basic soil properties and related experimental parameter settings used in the study. This includes information such as soil pH value, organic matter content, and nitrogen, phosphorus, and potassium

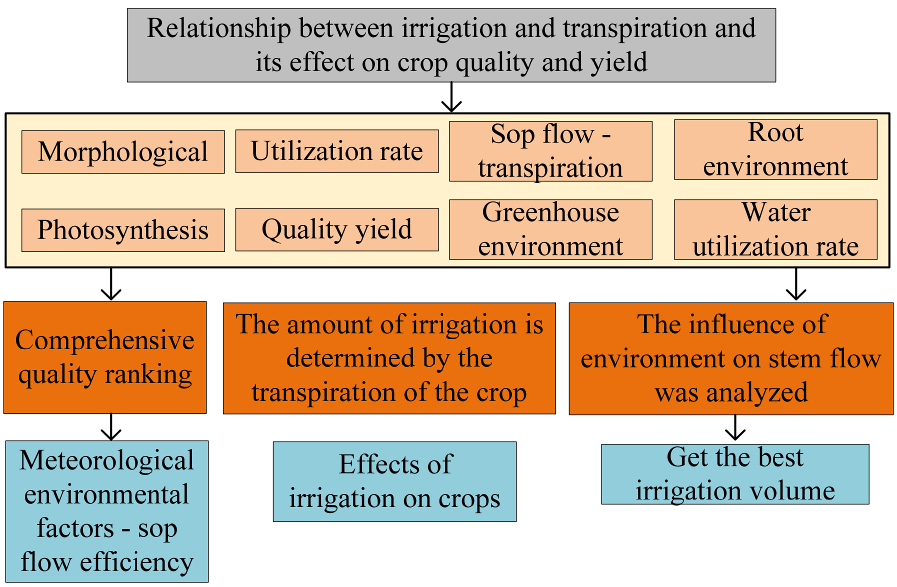

Figure 2. Research framework regarding the influence of transpiration-based irrigation on *Platycodon* crops.

contents, as well as the dosages of organic fertilizers applied. The setting of these experimental parameters provided a basis for the researchers to evaluate the impact of different parameters on the growth and quality of *Platycodon grandiflorus*.

The seeds used in this study were *Platycodon grandiflorus* seeds with purity of 99.9% and a germination rate of 96.9%. The seeds were provided by the research group. The fertilizer was a carbon-based organic fertilizer (total nitrogen, phosphorus, and potassium content of >8%; organic matter content of >46%; pH 6.0–8.0; water of <30%), provided by the research group. The nutrient solution was fully organic (nitrogen: 9275.972 mg/kg, phosphorus: 5063.231 mg/kg, potassium: 14,237 mg/kg).

Table 1. Basic properties of experimental soil and related experimental parameters.

<table>
<tr><th>Soil parameters</th><th>Parameter values</th><th>Treatment number</th><th>Treatment details</th><th>Planting parameters</th><th>Parameter values</th></tr>
<tr><td>Total porosity (%)</td><td>31.28</td><td rowspan="3">W1</td><td rowspan="3">80% of plant transpiration evaporation capacity per day</td><td rowspan="2">Detection depth of soil (cm)</td><td rowspan="2">0–30</td></tr>
<tr><td>Organic content (g/kg)</td><td>81.27</td></tr>
<tr><td>Total nitrogen content (g/kg)</td><td>3.24</td><td rowspan="2">Fertilizer application method</td><td rowspan="2">Applied once as a base fertilizer</td></tr>
<tr><td>Total phosphorus content (g/kg)</td><td>2.97</td><td rowspan="3">W2</td><td rowspan="3">100% of plant transpiration evaporation capacity per day</td></tr>
<tr><td>Total potassium content (g/kg)</td><td>7.20</td><td rowspan="2">Postemergence spacing (cm)</td><td rowspan="2">20</td></tr>
<tr><td>Alkali-hydrolyzed nitrogen content (g/kg)</td><td>16.97</td></tr>
<tr><td>Available phosphorus content (g/kg)</td><td>104.59</td><td rowspan="2">W3</td><td rowspan="2">120% of plant transpiration evaporation capacity per day</td><td rowspan="2">Spacing in rows (cm)</td><td rowspan="2">6</td></tr>
<tr><td>Available potassium content (g/kg)</td><td>55.12</td></tr>
</table>

After the completion of intercropping of the *Platycodon grandiflorus* crops, three plants were randomly collected every 10 days for each irrigation scheme, and they were labeled to measure plant height, stem diameter, and number of leaves.

After lignification occurred at the base of the aboveground parts of the *Platycodon grandiflorus* crops, the stem and leaf parts of the aboveground parts were harvested. The quality of the harvested plants was evaluated based on the contents of four components: saponins, flavonoids, polysaccharides, and soluble proteins.

In this study, the stemflow of *Platycodon grandiflorus* plants was studied and path analysis was conducted based on environmental factors (Wang et al., 2022). Figure 3 shows the interactions between environmental factors and stemflow, from which it can be concluded that environmental factors had both positive and negative impacts on stemflow. This helps in conducting more comprehensive and scientific analyses of stemflow. Specifically, the environmental factors that positively affected stemflow included saturated vapor pressure difference, net radiation value, air humidity, and water content. These factors promoted the occurrence and transmission of stemflow to a certain extent (Mishra et al., 2021). However, air humidity was found to have a negative impact on stemflow. Meanwhile, water content had a negative impact on stemflow efficiency through conductivity. In addition, irrigation volume regulated changes in electrical conductivity via synergistic effects on water content and fertilization, thereby affecting stemflow efficiency. The interaction of these factors interfered with the water and fertilizer transport processes of the *Platycodon* plants. In summary, the study of stemflow relationships was conducted based on environmental factors, providing an opportunity to gain a deeper understanding of the stemflow behavior of *Platycodon grandiflorus*. Through path analysis and the information provided in Figure 3, it is possible to better understand the impact of various environmental factors on stemflow and provide a scientific basis for optimizing stemflow effects.

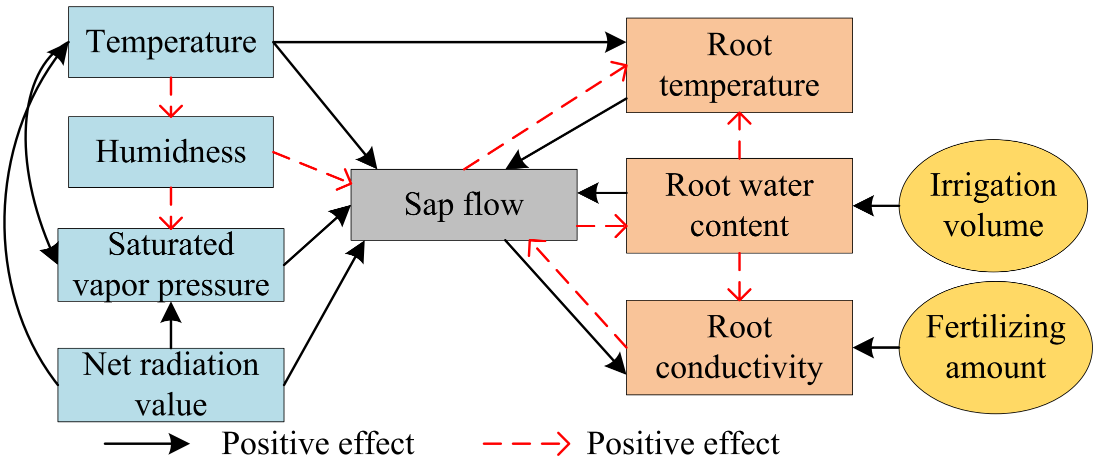

Figure 3. Stemflow–root–environment interaction diagram.

4. Experimental yield and quality results for *Platycodon grandiflorus* crops

The purpose of this study was to explore optimal irrigation schemes based on the transpiration of *Platycodon* crops by controlling irrigation in different amounts in order to achieve water-saving irrigation and maximize the yield of *Platycodon* crops. Although *Platycodon grandiflorus* prefers wetter soil, excessive irrigation may lead to root suffocation and even root rot, which can have extremely adverse effects on crop growth and development. Therefore, appropriate water quantity is crucial in irrigation, and correct irrigation management can also effectively improve the growth quality and yield of *Platycodon grandiflorus*.

4.1. Effects of different treatments on daily transpiration of *Platycodon grandiflorus*

As shown in Figure 4, results for weighed daily transpiration and evaporation and different treatment schemes were compared in this study. From Figure 4, it can be seen that from the 1st to the 15th day, the overall order of daily transpiration was W2 > W3 > W1, while after the 15th day, it was W3 > W2 > W1. This indicates that the water demands of the *Platycodon* crops during the flowering stage were met well by the W2 treatment scheme, with 100% irrigation, while during the maturity stage, the W3 scheme, with 120% irrigation, was suitable. W2 is more suitable for the growth of *Platycodon* crops during the flowering period, while W3 is more suitable for the growth of *Platycodon* during the maturity stage.

4.2. Effects of different treatments on stemflow of *Platycodon grandiflorus* under different weather conditions

In Figure 5, the influence of stemflow on sunny and cloudy days is shown. It can be observed that, overall, the stemflow rate increased with increasing irrigation amounts. Under cloudy conditions, the stemflow rate achieved with the W1 treatment ranged from 0 to 0.04 kg/h, while with the W2 treatment it ranged from 0.02 to 0.05 kg/h and with the W3 treatment it ranged from 0 to 0.13 kg/h. On a selected cloudy day, the active period of stemflow was from 08:00 to 18:00 hours, with 12:00 being the peak time of stemflow. Under sunny conditions, the stemflow rate achieved with the W1 and W2 treatments ranged from 0 to 0.1 kg/h, while the stemflow rate with W3 ranged from 0 to 0.45 kg/h. On a selected sunny day, the active period of stemflow was from 09:00 to 19:00 hours, with 14:00 being the peak. In summary, according to the results in Figure 5, under different weather conditions, the influence of irrigation amount on stemflow showed different trends. These findings have important reference value for crop irrigation management and water resource utilization.

4.3. Stepwise regression analysis of the impact of environmental factors on the stemflow of *Platycodon grandiflorus*

The environmental factors selected for analysis were temperature, air humidity, net radiation value, saturated vapor pressure difference, root temperature, water content, and conductivity. These indicators were used for stepwise regression analysis together with the stemflow rates of the *Platycodon* plants. The probability of the input factor was set to $F \leq 0.05$, and the probability of removing F was taken as ≥ 0.1. The stepwise regression models for different treatment schemes are shown in Table 2. In Table 2, SF represents stemflow velocity, T represents temperature, Rh represents air humidity, Rn represents net radiation value, VPD represents saturated vapor pressure, Ts represents root temperature, SWV represents water content, and EC represents conductivity. From Table 2, it can be seen that under cloudy conditions, the stemflow achieved with W1, W2, and W3 was mainly significantly correlated with Rn and T, while for W2 it was also significantly correlated with EC, SWV, and VPD. The remaining determining factors in the regression models of

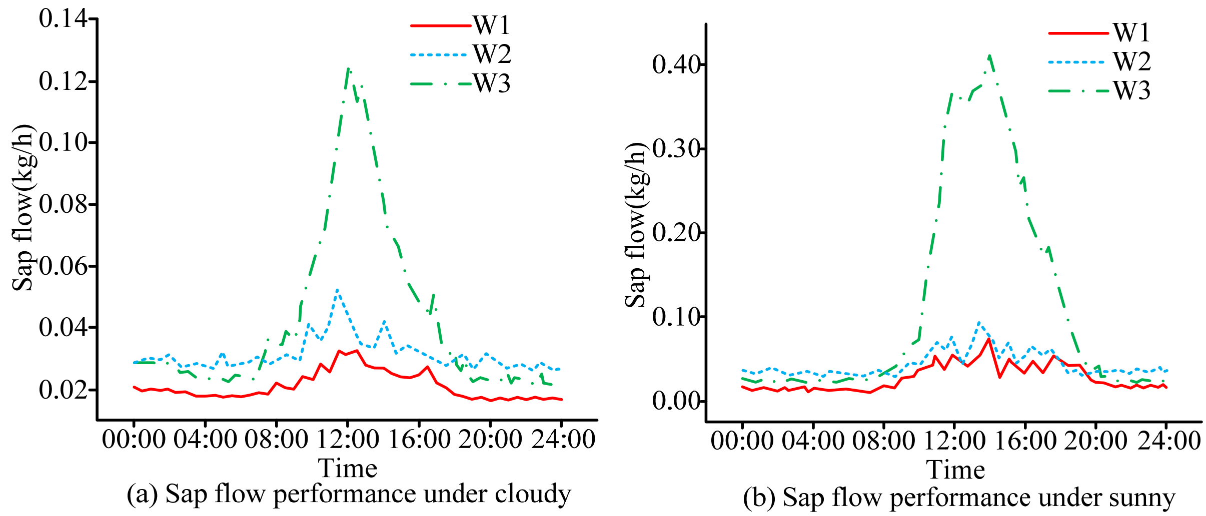

Figure 4. Daily evaporation of *Platycodon* crops.

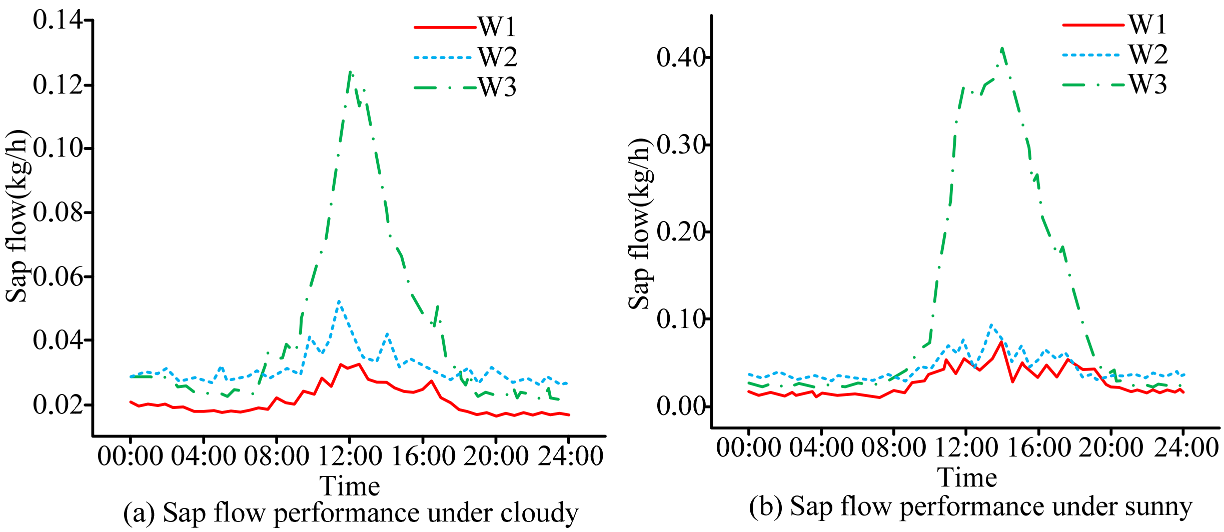

Figure 5. Effects of different treatments on stemflow.

W1, W2, and W3 under cloudy conditions were calculated as 0.042, 0.15, and 0.11, respectively. Under sunny conditions, W1 showed significant correlations with *Rn*, *VPD*, and *Rn*, while W2 showed significant correlations with *T*, *Ts*, and *SWV* and W3 showed a significant correlation with *EC*. The remaining determining factors in the regression models of W1, W2, and W3 under sunny conditions were calculated as 0.112, 0.053, and 0.006, respectively.

4.4. Correlation analysis of environmental factors and stemflow of *Platycodon grandiflorus*

For a more detailed analysis of the impact of environmental factors on the growth of *Platycodon grandiflorus*, and to further analyze the correlations between stemflow and environmental factors, analysis results are provided in Table 3. It can be seen that *T*, *Rh*, *Rn*, *VPD*, and *EC* had strong correlations with stemflow. The direct path coefficient of water content *SWV* was 0.089, and the direct path coefficients of net radiation *Rn* and conductivity for stemflow were 0.127 and 0.189, respectively. The decision coefficient of net radiation value *Rn* was the highest, with a value of 0.051. Therefore, it can be concluded that the synergistic effect of water content as determined by irrigation amount and conductivity caused by fertilization amount affected the stemflow efficiency of *Platycodon grandiflorus* crops and had a certain positive impact on water and fertilizer transportation efficiency.

Table 2. Optimal stepwise regression model for stemflow and environmental factors.

Weather conditions	Treatment	Stepwise regression model	Coefficient of determination R
Cloudy	W1	$SF = 0.672Rn + 0.542Ts - 0.298Rh$	$R = 0.957$
	W2	$SF = 0.428Rn + 0.715T - 0.298EC - 0$ $+0.105SWV$	$R = 0.824$
	W3	$SF = 0.428Rn + 0.715T - 0.384Rh$	$R = 0.892$
Sunny	W1	$SF = 0.492Rh - 0.28VPD - 0.64Rh$	$R = 0.897$
	W2	$SF = 0.482Rn + 1.345VPD - 0.215Rh +$ $+0.795Ts + 0.203SWV$	$R = 0.952$
	W3	$SF = 0.125Rn + 0.395VPD - 0.186Rh +$ $0.345Ts + 0.054SWV - 0.138EC$	$R = 0.989$

Table 3. Path analysis of environmental factors and stemflow of *Platycodon grandiflorus*.

-	Correlation coefficient	Direct path coefficient	Indirect path coefficient						Decision coefficient
			T	Rh	Rn	VPD	SWV	EC	
T	0.252	−0.003	-	0.002	0.004	−0.001	0.001	−0.002	−0.001
Rh	−0.252	−0.059	0.059	-	0.048	0.029	0.051	0.024	0.021
Rn	0.239	0.127	0.131	−0.121	-	0 .117	0.002	0.031	0.051
VPD	0.245	−0.012	−0.021	0.011	0.009	-	0.002	−0.004	−0.005
SWV	0.119	0.089	−0.004	0.009	−0.002	−0.004	-	−0.005	−0.004
EC	0.251	0.189	0.079	−0.087	0.061	0.081	−0.011	-	0.059

4.5. Effects of different treatments on morphological indicators of *Platycodon grandiflorus*

To analyze the optimal irrigation amount for *Platycodon grandiflorus*, the effects of different irrigation treatments based on transpiration on the morphological indicators of the crops were analyzed. The considered morphological indicators were plant height, stem diameter, and leaf number. These experimental results are shown in Figure 6. From Figure 6, it can be seen that the stem thickness of *Platycodon grandiflorus* varied in the order of W2 > W3 > W1 during the flowering stage and W3 > W2 > W1 during maturity. In the later growth stage of *Platycodon grandiflorus*, stem thickness increased more under the W3 treatment. The number of leaves varied in the order of W2 > W3 > W1 during flowering and W3 > W2 > W1 during maturity. For the plant height of *Platycodon grandiflorus*, the growth was relatively linear and varied in the order of W3 > W2 > W1 during the flowering stage. The growth rate of W3 was faster in the middle and early stages, but it slowed during maturity.

4.6. Effects of different treatments on the photosynthetic performance of *Platycodon grandiflorus*

In Table 4, the chlorophyll results for *Platycodon grandiflorus* crops under different treatments are presented. From Table 4, it can be seen that the overall contents of chlorophyll A and chlorophyll A/B at maturity were higher than those during the flowering stage. During the flowering stage, the specific chlorophyll contents under different treatments were evaluated in the order of W1 > W2 > W3, while at maturity, the order of chlorophyll contents was again W1 > W2 > W3 and there was no significant difference between W2 and W3. These findings indicate that the contents of chlorophyll generally decreased with increasing irrigation amounts.

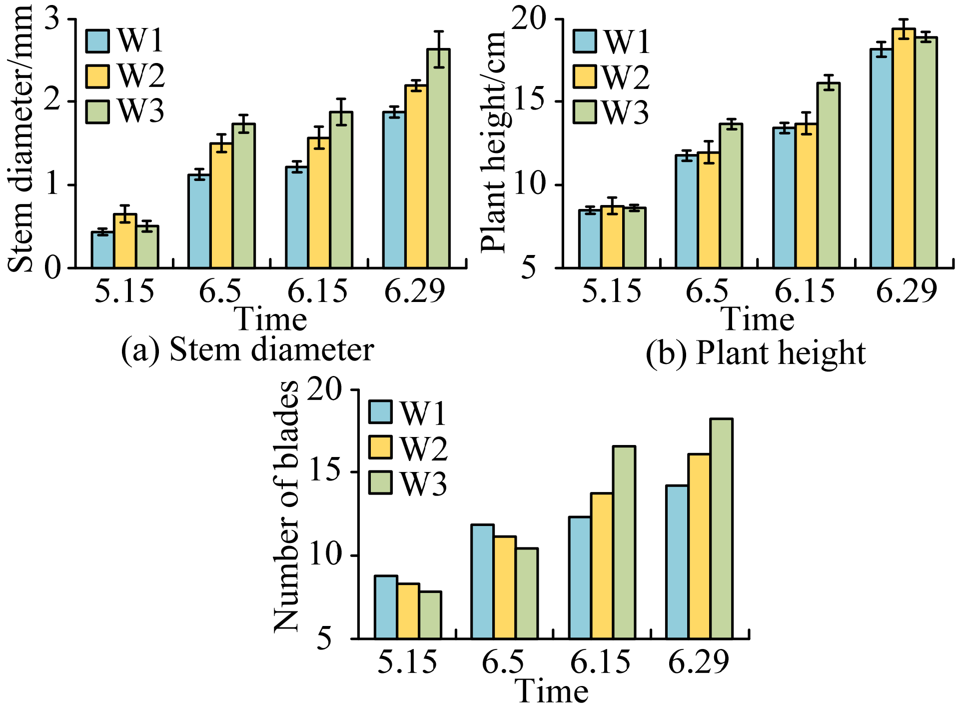

Figure 6. Effects of different irrigation treatments on crop morphological indexes of *Platycodon grandiflorus*.

In Table 5, results of the analysis of the impact of different irrigation treatments on the photosynthesis of *Platycodon grandiflorus* are presented. In Table 5, Np represents the photosynthetic rate, Tr represents the transpiration rate of *Platycodon grandiflorus* in the greenhouse, Sl represents the stomatal limit value of the *Platycodon* crops, Sc represents the stomatal conductance of the *Platycodon* crops, and A/E represents the ratio between net photosynthetic rate and transpiration rate. It can be seen that for stomatal conductance, during the flowering period, the specific order of expression was W2 > W1 > W3. Between W1 and W3, there was no significant difference. During the flowering period of *Platycodon grandiflorus*, the specific performance of the different treatments was found to be W3 > W2 > W1. For the stomatal limitation values of *Platycodon grandiflorus*, the order was W1 > W2 > W3. For the ratio between the net photosynthetic rate and the transpiration rate, the order during the flowering period was W1 > W2 > W3. At maturity, it was W3 > W2 > W1.

In Figure 7, the fluorescence kinetics curves of chlorophyll in *Platycodon grandiflorus* crops under different irrigation treatments are shown. It can be observed that with the increase in irrigation water volume, the chlorophyll fluorescence kinetics curve of *Platycodon grandiflorus* undergo significant changes. Specifically, the minimum fluorescence intensity under the different treatments occurred in the order of W1 > W3 > W2, while the order for maximum fluorescence intensity was W3 > W2 > W1. The minimum fluorescence intensity was measured under poor light conditions, indicating that light energy could not be effectively utilized. From Figure 7, it can also be observed that the minimum fluorescence intensity under the W1 treatment was highest, which may indicate lower photosynthetic efficiency with this treatment. In contrast, the minimum fluorescence intensity under the W3 treatment was lowest, which may indicate that the plants utilized light energy better under this treatment. On the other hand, the maximum fluorescence intensity was measured under good light conditions, reflecting the degree to which light energy was absorbed and utilized by plant leaves. As seen in Figure 7, the maximum fluorescence intensity was highest under the W3 treatment, while the maximum fluorescence intensity was lowest under the W1 treatment. This indicates that the plants treated with W3 could more effectively utilize light energy, which may lead to better photosynthetic efficiency and growth performance. Based on the results seen in Figure 7, the different irrigation treatments had a significant impact on the chlorophyll fluorescence kinetics curves of *Platycodon grandiflorus* crops. These changes may reflect differences in the photosynthetic efficiency and

Table 4. Effects of different irrigation treatments on chlorophyll contents of *Platycodon grandiflorus*.

Plant growth stage	Treatment	Chlorophyll A (mg/g FW)	Chlorophyll B (mg/g FW)	A + B (mg/g FW)	A/B (mg/g FW)
Flowering stage	W1	3.9 ± 0.00	6.9 ± 0.00	10.8 ± 0.00	0.5 ± 0.00
	W2	3.6 ± 0.00	6.0 ± 0.00	9.6 ± 0.00	0.6 ± 0.00
	W3	3.3 ± 0.00	5.4 ± 0.00	8.7 ± 0.00	0.6 ± 0.00
Maturity stage	W1	6.4 ± 0.00	2.9 ± 0.00	9.3 ± 0.00	2.2 ± 0.00
	W2	5.1 ± 0.00	2.4 ± 0.00	7.5 ± 0.00	2.1 ± 0.00
	W3	4.8 ± 0.00	2.2 ± 0.00	7.0 ± 0.00	2.2 ± 0.00

Table 5. Effects of different irrigation treatments on the photosynthesis of *Platycodon* crops.

Plant growth stage	Treatment	Np (μmol/m²/s)	Sc (mol/m²/s)	Tr (mmol/m²/s)	Sl	A/E
Flowering stage	W1	20.72 ± 1.09	0.68 ± 0.04	7.89 ± 0.39	0.12 ± 0.02	2.68 ± 0.02
	W2	23.65 ± 0.29	1.58 ± 0.28	11.67 ± 0.68	0.08 ± 0	2.01 ± 0.19
	W3	21.79 ± 0.25	1.46 ± 0.25	11.42 ± 0.72	0.07 ± 0.01	1.91 ± 0.14
Maturity stage	W1	24.28 ± 0.28	0.91 ± 0.07	18.72 ± 0.51	0.84 ± 0.01	1.42 ± 0.04
	W2	25.57 ± 0.27	0.99 ± 0.01	18.93 ± 0.48	0.82 ± 0.01	1.45 ± 0.04
	W3	26.58 ± 1.28	1.05 ± 0.12	19.42 ± 0.08	0.83 ± 0.01	1.48 ± 0.05

growth status of *Platycodon grandiflorus* under different irrigation conditions. Therefore, in actual planting, selecting appropriate irrigation treatment methods can help to maximize the photosynthetic efficiency and yield of *Platycodon grandiflorus*.

In Figure 8, impact analysis of the different irrigation treatments on the photochemical system performance of *Platycodon grandiflorus* is presented. In Figure 8, Fv/Fm represents the maximum photon efficiency, Pi_{ABS} represents the efficiency index, ABS/RC represents the energy absorbed by the active reaction center, Dio/RC represents the energy dissipated per unit light area, Tro/RC represents the energy obtained by the plant's reaction center and used for converting reduction energy, and Eto/RC represents the quantum yield used for electron transfer in the reaction center. From Figure 8, it can be seen that for Fv/Fm and Pi_{ABS}, different treatments resulted in an order of W3 > W2 > W1. For ABS/RC and Dio/RC, the order was W1 > W2 > W3. For Tro/RC and Eto/RC, the order was W1 > W3 > W2.

4.7. Effect of different treatments on the yield of *Platycodon grandiflorus*

In Table 6, the effects of different irrigation treatments on the yield of *Platycodon grandiflorus* are shown. It can be observed that the yield of the W3 treatment was higher

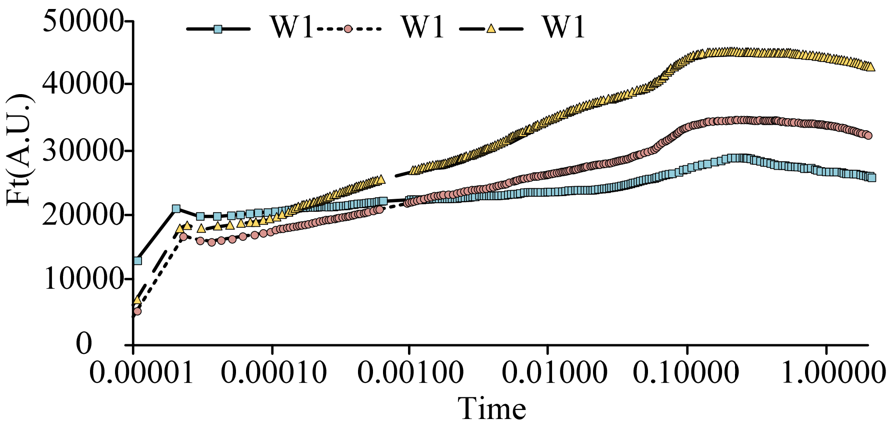

Figure 7. Chlorophyll fluorescence kinetics curves under different irrigation treatments.

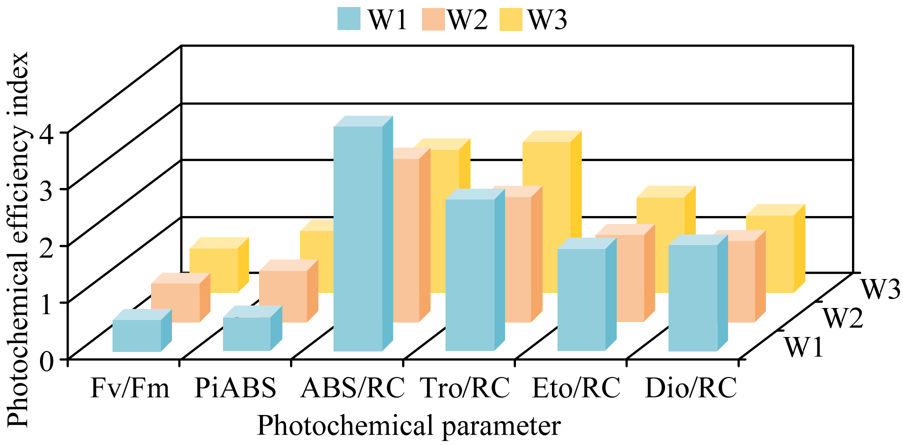

Figure 8. Photochemical performance parameters under different irrigation treatments.

than that of W2, while the yield of the W2 treatment was higher than that of W1. In research conducted on a sunny day, it was found that the W3 treatment had the best impact on the yield of *Platycodon grandiflorus*. This was because, on sunny days, the crops required more water to satisfy their growth needs, so increasing irrigation volumes actively promoted the increase in plant yield. However, different trends were observed under cloudy conditions, whereby the yield of the W2 treatment was higher than that of W1, while the yield of the W3 treatment was significantly lower than that of W1 and W2. This was because, under cloudy conditions, the water demand of the crops decreased, and excessive irrigation had a negative impact on normal development and growth. In this case, the irrigation amount of the W3 treatment exceeded the demands of the plants, resulting in a significantly lower yield for the W3 treatment compared to W1 and W2. Overall, these research results indicate that under different weather conditions, the impact of irrigation volume on the yield of *Platycodon grandiflorus* varies. On sunny days, increasing the irrigation volume is beneficial for increasing the yield. In cloudy weather, excessive irrigation has a negative impact on yield. Therefore, in the actual process of planting *Platycodon grandiflorus*, appropriate irrigation management needs to be carried out based on weather conditions and the water needs of the plants to maximize the yield.

4.8. Effects of different treatments on the quality of *Platycodon grandiflorus*

In Figure 9, the effects of different irrigation treatments on the quality of *Platycodon grandiflorus* are shown. The contents of saponins, flavonoids, polysaccharides, and soluble proteins were selected as indicators for analyzing the quality of *Platycodon grandiflorus* in this study. From

Table 6. Effects of different irrigation treatments on yield of *Platycodon grandiflorus*.

Weather conditions	Treatment	Yield per plant (g)	Regional production (g)	Equivalent yield per hectare (kg)
Sunny	W1	9.68 ± 0.34	785.27 ± 29.38	492.36 ± 17.68
	W2	11.07 ± 0.42	872.92 ± 31.07	558.39 ± 19.52
	W3	12.04 ± 0.58	904.38 ± 29.69	614.28 ± 21.96
Cloudy	W1	10.76 ± 0.42	859.28 ± 28.69	469.37 ± 22.76
	W2	11.52 ± 0.51	927.36 ± 36.47	619.57 ± 22.81
	W3	8.24 ± 0.27	621.89 ± 29.64	385.21 ± 19.37

Figure 9, it can be observed that in terms of overall quality, the performance under different treatments was achieved in the order of W3 > W2 > W1. The W2 treatment had the best quality performance in terms of soluble protein contents in the *Platycodon* crops. This may be because too much or too little irrigation can have an impact on the synthesis of nutrients in *Platycodon grandiflorus*, and the W2 treatment effectively balanced the relationship between nutritional needs and irrigation water volume. However, for the contents of saponins, flavonoids, and polysaccharides, the W3 treatment had the best quality performance. This may be because excessive irrigation helps to create a suitable soil environment for the growth of *Platycodon grandiflorus*, thereby increasing the synthesis and accumulation of these nutrients. In addition, excessive irrigation can also help improve the water and fertilizer utilization efficiency of *Platycodon* crops. Overall, according to Figure 9, the different irrigation treatments had a significant impact on the quality of *Platycodon grandiflorus*. Optimal treatment was based on the indicators of concern, such as soluble protein, saponins, flavonoids, and polysaccharide contents. These findings emphasize the importance of irrigation management in affecting the quality of *Platycodon* crops, providing guidance for growers to improve yield and quality.

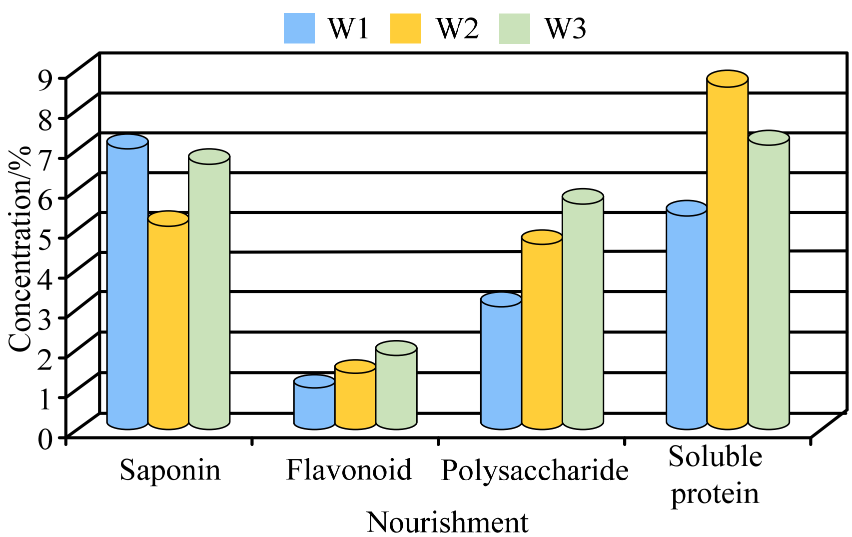

Figure 9. Effect of different irrigation treatments on the quality of *Platycodon grandiflorus*.

5. Conclusion

In order to maximize water resource utilization and increase the yield of *Platycodon grandiflorus* crops, the optimal irrigation method for these crops was explored in the present study. The study was based on the transpiration rate of *Platycodon grandiflorus* crops and different irrigation rates were applied. The effects of the different irrigation rates on multiple indicators of *Platycodon grandiflorus* were explored, including daily transpiration rate, stemflow rate, morphological indicators, photosynthetic performance, yield, and quality. For the daily transpiration of *Platycodon grandiflorus*, the demand for water varies during different periods. In the flowering stage, the order was W2 > W3 > W1, while in maturity, it was W3 > W2 > W1. For the stemflow rate of *Platycodon grandiflorus* crops, both cloudy and sunny days produced an order of W3 > W2 > W1, but the overall stemflow rate was sunny > cloudy. For the morphological indicators of *Platycodon*, the number of leaves during flowering was obtained in the order of W1 > W2 > W3, while at maturity it was W3 > W2 > W1. For photosynthetic performance, the results showed that chlorophyll contents varied in the order of W1 > W2 > W3, while for net photosynthetic rate the order was W2 > W3 > W1, and for the photosynthetic efficiency index it was W3 > W2 > W1. For the yield of *Platycodon*, there were differences under different weather conditions, with an order of W2 > W3 > W1 under cloudy conditions and W3 > W2 > W1 under sunny conditions. For quality, the overall performance was in the order of W3 > W2 > W1, while for total soluble protein contents, the order was W2 > W3 > W1. In summary, for these *Platycodon* crops, there were different optimal irrigation treatment methods at different growth stages and temperature conditions. While 100% transpiration irrigation was required during the flowering stage, 120% transpiration irrigation was required during maturity. This is because more nutrients are used for reproductive growth during the flowering stage of the crop, while more leaves tend to grow during maturity. For *Platycodon* crops, an increase in temperature requires an appropriate increase in irrigation volume, while a decrease in temperature requires an appropriate reduction in irrigation volume. This study did not take into account the effects of other factors such as fertilizers and soil on the growth and development of *Platycodon grandiflorus* crops, and improvements should be made in this regard in further research.

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References

Arora C, Kamat A, Shanker S, Barve A (2022). Integrating agriculture and industry 4.0 under 'agri-food 4.0' to analyze suitable technologies to overcome agronomical barriers. British Food Journal 7: 2061-2095. https://doi.org/10.1108/BFJ-08-2021-0934

Cass BN, Hack LM, Mueller TG, Buckman D, Grafton-Cardwell EE et al (2020). Arthropod infestation levels on mandarins in California. Journal of Economic Entomology 113: 2335-2342. https://doi.org/10.1093/jee/toaa141

Deng X, Xu D, Zeng M, Qi Y (2020). Does outsourcing affect agricultural productivity of farmer households? Evidence from China. China Agricultural Economic Review 12: 673-688. https://doi.org/10.1108/CAER-12-2018-0236

Echchelh A, Hess T, Sakrabani R, Prigent S, Stefanakis AI (2021). Towards agro-environmentally sustainable irrigation with treated produced water in hyper-arid environments. Agricultural Water Management 243: 106449-106460. https://doi.org/10.1016/j.agwat.2020.106449

Eckardt NA, Ainsworth EA, Bahuguna RN, Broadley MR, Busch W et al. (2023). Climate change challenges, plant science solutions. Plant Cell 35: 24-66. https://doi.org/10.1093/plcell/koac303

Fasusi OA, Babalola OO (2021). The multifaceted plant-beneficial rhizobacteria toward agricultural sustainability. Plant Protection Science 57: 95-111. https://doi.org/10.17221/130/2020-PPS

Harris BA, Florkowski WJ, Pennisi SV (2020). Horticulture industry adoption of biodegradable containers. HortTechnology 30: 372-384. https://doi.org/10.21273/HORTTECH04563-19

Helal E, Shaban M, El-Karim EA, Ellayen A (2021). A comprehensive management model to maximize the benefits of agriculture drainage water reuse. Water Environment Research 93: 1722-1733. https://doi.org/10.1002/wer.1559

Irik HA, Kirnak H (2022). Evaluation of spectral vegetation indices for drip irrigated pumpkin seed under semi-arid conditions. Arabian Journal of Geosciences 15: 86110-86111. https://doi.org/10.1007/s12517-022-10136-z

Jeet P, Singh DK, Sarangi A, Mali SS, Singh AK (2022). Delineation of potential water harvesting site for agriculture water planning in Betwa basin of India using geospatial and analytical hierarchical process technique. Geocarto International 37: 8315-8335. https://doi.org/10.1080/10106049.2021.2000647

Khan Z, Wild TB, Iyer G, Hejazi M, Vernon CR (2021). The future evolution of energy-water-agriculture interconnectivity across the US. Environmental Research Letters 16: 65010-65014. https://doi.org/10.1088/1748-9326/ac046c

Lowe T, Moghadam P, Edwards E, Williams J (2021). Canopy density estimation in perennial horticulture crops using 3D spinning lidar SLAM. Journal of Field Robotics 38: 598-618. https://doi.org/10.1002/rob.22006

Mazzia V, Comba L, Khaliq A, Chiaberge M, Gay P (2020). UAV and machine learning based refinement of a satellite-driven vegetation index for precision agriculture. Sensors 20: 2530-2543. https://doi.org/10.3390/s20092530

Millard K, Brown N, Stiff D, Pietroniro A (2020). Automated surface water detection from space: a Canada-wide, open-source, automated, near-real time solution. Canadian Water Resources Journal 45: 304-323. https://doi.org/10.1080/07011784.2020.1816499

Mishra AK, Pujari PR, Dhyani S, Verma P, Janipella R et al. (2021). Assessing water requirement of orange trees using sap flow measurements in Narkhed-Pandhurna critical zone observatory (CZO) in central India. Journal of Agrometeorology 23: 14-20. https://doi.org/10.54386/jam.v23i1.83

Nemacheck JA, Flynn RD, Zapf K, Subramanyam S (2023). Identification of new sources of Hessian fly resistance in tetraploid wheat. Crop Science 63: 1354-1363. https://doi.org/10.1002/csc2.20917

Qu Y, Kang J, Lin X, Ni H, Jiang Y et al. (2022). Analysis of agriculture water pricing reform in a water-deficit area of Northwest China. Water Policy 24: 1570-1589. https://doi.org/10.2166/wp.2022.288

Van Asselt ED, Banach JL, Kluche M, Appelman WAJ (2021). Prioritising water disinfection technologies to improve food safety of leafy vegetables. British Food Journal 123: 1899-1912. https://doi.org/10.1108/BFJ-03-2020-0197

Vishnoi L, Kumar A, Kumar S, Sharma G, Baxla AK et al. (2021). Review Paper: Weather based crop insurance for risk management in agriculture. Journal of Agrometeorology 22: 101-108. https://doi.org/10.54386/jam.v22i2.149

Wang D, Saleh NB, Byro A, Zepp R, Sahle-Demessie E et al. (2022). Nano-enabled pesticides for sustainable agriculture and global food security. Nature Nanotechnology 17: 347-360. https://doi.org/10.1038/s41565-022-01082-8

Wu Z, Zhao Y, Zhang N (2023). A literature survey of green and low-carbon economics using natural experiment approaches in top field journal. Green and Low-Carbon Economy 1: 2-14. https://doi.org/10.47852/bonviewGLCE3202827

Zhao F, Zhao SX, Wang RY, Zhang K, Wang HL et al. (2020). Quantifying key model parameters for wheat leaf gas exchange under different environmental conditions. Journal of Integrative Agriculture 9: 2188-2205. https://doi.org/10.1016/S2095-3119(19)62796-6