RESEARCH ARTICLE

The influence of different cultivation modes on the growth traits of roses

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Protected cultivation of cut roses has become the core model for their large-scale production, but conventional soil cultivation is prone to continuous cropping obstacles, deterioration of soil physical and chemical properties, and frequent occurrence of diseases and pests, which seriously restrict the growth quality and production efficiency of cut roses. This study aimed to explore the effects of different cultivation modes on the growth traits of cut rose varieties to provide a theoretical basis for the high-quality and efficient cultivation of protected cut roses. Taking cuttings of single-headed cut rose variety 'Jinshe' and multi-headed cut rose variety 'Tianxin Wuyu' as test materials, three cultivation modes were set up including substrate cultivation (T1), soil-improved cultivation (T2), and conventional soil cultivation (T3). The physical properties of cultivation media, growth traits such as survival rate, plant height, and stem diameter were determined, disease investigation was conducted, and correlation analysis and principal component analysis (PCA) were performed to screen out the optimal cultivation mode. The results showed that, on the 30th day of the vegetative growth stage of rose cuttings, the physical properties of cultivation media, cutting survival rate, plant height, stem diameter, branch number, leaf number, and relative chlorophyll content assessed using soil and plant analysis development (SPAD) value in T1 and T2 were all better. The bulk density of T1 and T2 decreased by 87.7% and 12.3%, respectively, compared with T3. The disease plant rate of single-headed variety in T2 decreased by 61.5% compared with T3. The maximum stem diameters of single-headed and multi-headed varieties in T2 were 3.0 mm and 3.06 mm, respectively, which increased by 25.12% and 9.83%, respectively, compared with T3. The leaf numbers of single-headed varieties in T1 and T2 increased by 6.41% and 17.76%, respectively, compared with T3. The SPAD values of single-headed (S) and multi-headed varieties (D) in T2 increased by 7.76% and 8.49%, respectively, compared with T3. The comprehensive evaluation score ranking of principal component analysis was T2S > T1S > T2D > T1D > T3S > T3D. Compared with T3, T1 and T2 were more conducive to the growth of cut roses, which could significantly improve the agronomic traits of roses at the vegetative growth stage, enhance plant stress resistance, and reduce the incidence of diseases and pests. The comprehensive effect of T2 was the best, especially suitable for single-headed rose varieties. This study systematically elucidated the adaptive mechanisms between different cultivation patterns and the growth characteristics and stress resistance of single-headed and multi-headed cut roses, determined the regulatory role of the physical properties of the cultivation substrate on plant growth, and provided scientific support for the comprehensive management of continuous cropping obstacles in protected roses and the innovation of high-quality and efficient production technologies.

Keywords: soil improvement; cultivation mode; rose; variety; growth trait.

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Introduction

Roses (*Rosa hybrida*) as the members of the *Rosaceae* family and the *Rosa genus* are the celebrated ornamental flowers and are ranked among the four most significant cut flower varieties worldwide [1]. These cut roses often referred to as "modern roses" and are the result of extensive hybridization of native species within the genus [2]. As one of the highest-value and most widely consumed cut flower varieties globally, these roses have a quality and yield that profound impact on the economic viability and sustainable development of the floral industry [3]. Yunnan province of China stands out as a major production area for cut roses, benefiting from a unique climate that contributes to its significant output, which accounts for over 70% of the nation's total production and plays a crucial role in the local agricultural economy [4]. However, the practice of prolonged monoculture has led to several challenges including soil compaction [5], increased bulk density, reduced porosity, and the deterioration of soil structure [6], all of which hinder the green and sustainable development of Yunnan's floral industry. Moreover, the inherent characteristics of different flower varieties coupled with considerable differences in cultivation methods highlight the necessity of investigating effective cultivation modes for various species.

Previous research has explored the application of soilless cultivation and soil improvement technologies in agricultural production. Zhao *et al*. found that the nutrient content in substrate cultivation of cut roses was over four times greater than that of soil-based cultivation. Their research revealed that, while the nitrogen, potassium, calcium, and zinc levels in soil cultivation were slightly lower than those in substrate cultivation, phosphorus, iron, and magnesium contents were notably higher [7]. Xiong *et al*. demonstrated that, under identical greenhouse conditions, substrate cultivation yielded superior production levels, heavier individual fruit weights, and enhanced disease resistance compared to soil cultivation [8]. Similarly, Liu *et al*. indicated that substrate cultivation significantly improved the net photosynthetic rate of tomatoes, enhancing fruit quality, specifically increasing levels of lycopene and vitamin C when compared with soil cultivation [9]. In addition, the research concerning the soilless cultivation of chrysanthemums revealed marked differences in growth performance between various artificial substrates and traditional soil cultivation [10]. Furthermore, research on soil amendments had indicated that substances such as humic acid and straw turnover could effectively regulate soil structure and improve moisture and nutrient retention, thereby supporting the application of biological organic fertilizers in agricultural practices [11-13]. Zhang *et al*. highlighted that the use of biological organic fertilizers could reduce the bulk density of potted soil by 5.5% to 9.5% [14]. Similarly, Su *et al*. demonstrated that increased applications of biological organic fertilizers promoted chlorophyll synthesis in leafy vegetables, leading to enhanced plant height, leaf count, and thickness, as well as improved yields, alongside increases in soil organic matter, effective phosphorus, and readily available potassium [15]. Despite the plethora of research focusing on substrate cultivation or conventional soil methods, there remains a scarcity of systematic comparisons among substrate, soil amendment, and conventional soil cultivation modes. Furthermore, the response of specific rose varieties to these cultivation modes has not been thoroughly explored, particularly concerning the adaptability differences between single-head and multi-head roses.

This research investigated the effects of various cultivation modes on the physical properties of the cultivation medium and their implications for disease incidence, survival rates, plant height, stem diameter, branch count, leaf number, and soil and plant analysis development (SPAD) values across different cut rose varieties using correlation and principal component analysis to illuminate the adaptability and growth characteristics of various rose species. The results of this research would provide a comprehensive evaluation of the strengths and weaknesses of different cultivation modes, laying the groundwork for variety-specific cultivation strategies to advance the floral industry toward more efficient, high-quality, and ecologically sustainable practices. Such efforts would enhance China's competitiveness in the cut rose market and protect its agricultural ecological environment.

Materials and methods

The rose cuttings varieties and treatments

The rose cuttings of single-head rose variety, "Poetic Zither" (Jinse), and the multi-head rose variety, "Sweetheart's Tale" (Tianxin Wuyu), were provided by Kunming Jinyuan Floral Industry Co., Ltd. (Kunming, Yunnan, China) with the cuttings being 30 days old. The experimental site was located at a latitude of 24°93′74″ and a longitude of 102°54′05″ with an elevation of 1,860 m and an area of 1,333 m^2. The soil was characterized as loamy with a neutral pH, excellent moisture retention, comprehensive irrigation facilities, an abundant water supply, and good drainage conditions. Three distinct cultivation modes including substrate cultivation (T1), soil amendment cultivation (T2), conventional soil (T3) and two roses of single-head (S) and multi-head (D) were included in this study. The T1 mode utilized a mixture of coconut coir, perlite, and expanded clay in the proportions of 60%, 15%, and 25%, respectively. The T2 mode involved deep plowing and soil amendment with 5 tons of biological organic fertilizer containing of 30% Zhaotong humic acid, 30% chrysanthemum residue, and 30% tobacco residue along with 10% of a mixture containing distillers' grains, fish protein, rapeseed cake, potassium humate, and tobacco potassium at a pH of 7.28 (Yunnan Kaimeiguan Biotechnology Co., Ltd., Qujing, Yunnan, China) per acre prior to planting. The T3 mode required no treatment, allowing for direct planting. On August 20, 2024, a uniform selection of rose cuttings was transplanted with each cultivation mode accommodating both rose varieties. A single ridge double-row planting system was employed with a plant spacing of 15 cm and a row spacing of 30 cm. A total of 90 cuttings were planted per treatment with three replicates each consisting of 30 cuttings. All three cultivation modes adhered to the same routine water and fertilization management practices.

Determination of physical properties of cultivation substrates

30 days post-transplantation of the roses during the growth period, soil from the cultivation layers of 0 to 20 cm of all 3 modes were collected using a five-point sampling method [16]. The physical properties of the collected soils were assessed by using the "Comprehensive Physicochemical Property Determination Method for Cultivation Substrates" [17], which included measurements of bulk density (BD), water-holding capacity (θf), total porosity (TP), aeration porosity (AFP), water-holding porosity (HWP), and the air-to-water ratio.

Investigation of diseases and calculation of disease indices

The occurrence of diseases during the growth period of roses was surveyed using a five-point sampling method, where two rose plants were marked at each point. All leaves of each plant were examined with three replicates for each treatment. The disease incidence and severity indices for the two rose varieties across the three cultivation modes were calculated. The disease severity rating scale was that 0 points indicated no symptoms, 1 point indicated that the lesion area was less than 5% of the total leaf area, 3 points indicated that the lesion area was 5.1 - 10% of the total leaf area, 5 points indicated that the lesion area was 10.1 - 25% of the total leaf area, 7 points indicated that the lesion area was 25.1 - 50% of the total leaf area, 9 points indicated that the lesion area was more than 50% of the total leaf area. The disease incidence rate and index (DI) were calculated as follows.

$$\text{Disease incidence rate} = \frac{\text{Number of Infected Plants}}{\text{Total Number of Plants Sampled}} \times 100\% \quad (1)$$

Table 1. Physical properties of different substrates under different cultivation modes (mean ± standard deviation).

Cultivation mode	T1	T2	T3
Bulk density (BD) (g/cm^3)	0.15 ± 0.01^c	1.07 ± 0.03^b	1.22 ± 0.02^a
Water holding capacity θf (%)	490.54 ± 18.14^a	153.10 ± 10.52^b	137.96 ± 2.92^b
Total porosity (TP) (%)	79.17 ± 9.20^a	70.57 ± 3.92^a	49.03 ± 10.54^b
Aeration porosity (AFP) (%)	20.42 ± 1.06^a	19.91 ± 0.78^a	16.24 ± 1.57^b
Water-holding porosity (HWP) (%)	58.76 ± 9.90^a	50.66 ± 3.22^a	8.35 ± 2.50^b
Air-water ratio (%)	0.35 ± 0.06^b	0.39 ± 0.02^b	2.05 ± 0.51^a

Note: Different lowercase letters in the same column indicated significant differences between different treatments ($P < 0.05$).

$$DI = \Sigma \frac{(\text{No. of diseased leaves at each scale} \times \text{Representative value of each scale})}{(\text{Total number of diseased leaves} \times 9)} \times 100 \quad (2)$$

Determination of growth traits

During the growth period of the roses, the survival rates of cuttings, plant height, stem diameter, number of branches, and leaf count for the different rose varieties under various cultivation treatments were recorded.

Measurement of Leaf SPAD Values

In the growth period of the roses, the fourth compound leaf from beneath the terminal bud was selected with measurements taken from the middle, broader region of the leaflets. The chlorophyll contents of 15 leaf samples were assessed using the SPAD-TYS-A chlorophyll meter (Zhongke Weihe Technology Development Co., Ltd., Beijing, China). The average value was recorded as the relative SPAD content.

Data processing and statistical analysis

All data were processed using Microsoft Excel 2021 (Microsoft, Redmond, WA, USA). SPSS 26.0 software (IBM, Armonk, NY, USA) was employed for statistical analysis of this study. Duncan's test was used to analyze the difference significance with *P* value less than 0.05 defined as statistically significant. A Pearson correlation analysis was conducted on the growth indicators of rose height, stem diameter, leaf count, SPAD values, and branch number. Further, a principal component analysis (PCA) was performed to evaluate multiple indicators by applying the idea of dimensionality reduction, which transformed the original indicators into a few uncorrelated comprehensive indicators referred to as principal components [18]. A comprehensive score was calculated. All graphical representations were generated by utilizing OriginPro 2025 software (https://www.originlab.com).

Results

Comparison of physical properties of growing media under different cultivation modes

Among the three cultivation modes, the bulk density of the growing media was notably lower in T1 and T2 compared to T3, indicating that T1 and T2 possessed superior structural properties compared to conventional soil. In terms of water retention capacity, T1 significantly surpassed both T2 and T3 ($P < 0.05$), showcasing enhanced moisture retention. The total porosity measurements revealed that T1 and T2 were significantly greater than T3, suggesting that both T1 and T2 effectively enhanced overall porosity, while T3 exhibited lower total porosity and inferior structure. Aeration porosity and water-holding porosity were also found to be significantly higher in T1 and T2 compared to T3 ($P < 0.05$), which indicated that T1 and T2 could improve both aeration and water retention. The air-to-water ratio was the highest in T3 and significantly greater than that in T1 and T2, while T1 and T2 showed no significant difference between them. These results suggested that T1 and T2 provided a more harmonious balance of aeration and water retention, thus facilitating root growth in roses (Table 1). Overall, the physical properties of the growing media in T1 and T2 including bulk density and porosity were superior to those in T3, thereby offering a more favorable environment for optimal root aeration

Table 2. Investigation on diseases of roses under different cultivation modes.

Treatment	Total number of plants surveyed	Diseased plant rate (%)	Disease index
T1S	30	10 ± 1.90^{cd}	1.44 ± 0.47^{d}
T1D	30	11.11 ± 2.06^{bc}	1.67 ± 0.56^{d}
T2S	30	5.56 ± 1.23^{e}	2.39 ± 0.11^{c}
T2D	30	6.67 ± 1.39^{de}	2.42 ± 0.32^{c}
T3S	30	14.44 ± 2.67^{b}	4.42 ± 0.39^{a}
T3D	30	25.56 ± 5.23^{a}	3.54 ± 0.26^{b}

Note: Different lowercase letters in the same column indicated significant differences between different treatments ($P < 0.05$).

and water retention in roses. Moreover, T1 exhibited a distinctly superior water retention capacity compared to T2 and T3.

Investigation of rose diseases under different cultivation modes

The results showed that the cultivation mode significantly affected both the incidence of diseased plants and the disease index of roses ($P < 0.05$). Among the three cultivation modes, the disease incidence demonstrated that, with the exception of single-head roses in conventional soil cultivation (T3S), both T1 and T2 exhibited a significantly lower incidence of diseased plants compared to T3, indicating that T1 or T2 could markedly reduce the incidence of disease in both rose varieties. Additionally, no significant difference was observed in the disease incidence between the two varieties under T1 and T2 treatments. Conversely, under the T3 treatment, the incidence of disease among single-head (S) and multi-head (D) roses was the highest and statistically significant, suggesting that conventional soil had a variable impact on the disease incidence of the two varieties with the disease incidence of T3D significantly surpassing that of T3S. Regarding the disease index, both T1 and T2 significantly outperformed T3, indicating that T1 and T2 could substantially reduce the disease index in both varieties. Similar to disease incidence, no significant differences were noted in the disease index of the two varieties under T1 and T2 treatments. However, under the T3 treatment, T3S and T3D had the highest disease indices with marked differences, revealing that conventional soil affected the disease index inconsistently between the two varieties with T3S showing a significantly higher disease index than T3D (Table 2). Overall, T1 and T2 effectively reduced the disease incidence and disease index in both single-head and multi-head roses, while T3 exhibited the highest rates of disease incidence and disease index among varieties, demonstrating significant differences. Therefore, T2 emerged as the most advantageous choice for lowering disease incidence and disease index in both rose varieties.

The influence of different cultivation modes on the survival rate of rose cuttings

The cultivation mode significantly affected the survival rate of rose cuttings ($P < 0.05$). The survival rates under the three modes revealed that T1 and T2 were considerably higher than T3, indicating that either T1 or T2 could enhance the survival rates of rose cuttings, while T3 provided insufficient support for survival. Under the T1 treatment, the survival rate of T1D was significantly greater than that of T1S, demonstrating differing adaptability between the two varieties in the substrate. In the context of T2, the survival rates of T2S and T2D were notably similar and both relatively high, suggesting that the soil amendment fostered compatibility for both varieties with the single-head variety exhibiting a slight advantage over T1 under T2 conditions. Conversely, under T3 treatment, both T3S and T3D demonstrated the lowest survival rates with no significant differences, indicating that conventional soil inadequately supported the survival of both varieties and that the differences in variety adaptability were not evident in T2 and T3 modes (Figure 1). Overall, both T2 and T1 significantly improved the survival rates of single-head and multi-head rose cuttings with T2 demonstrating particularly pronounced effects for the single-head variety. T3 yielded the lowest survival rates and provided minimal support for both varieties. Therefore, T2 emerged as the optimal choice for enhancing the survival rate of rose cuttings.

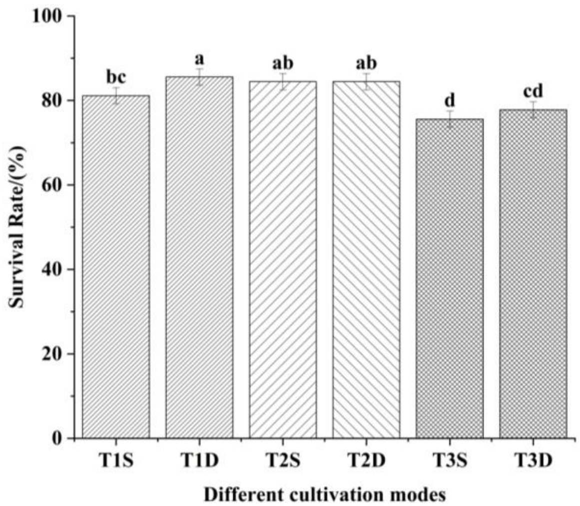

Figure 1. Effects of different cultivation modes on cutting survival rates of roses. The different lowercase letters in the same column indicated significant difference between different treatments (P < 0.05).

The influence of different cultivation modes on the height of rose plants

The results showed that the cultivation mode significantly influenced the height of rose plants (P < 0.05). The observed heights under the three modes indicated that T1 and T2 were notably greater than T3, suggesting that both T1 and T2 could significantly enhance the height of the two rose varieties compared to T3. Within the T1 treatment, T1S exhibited a significantly greater height than T1D, indicating a marked difference in growth status between the two varieties in the substrate with single-head roses growing at a notably faster rate than their multi-head counterparts. Under the T2 treatment, both T2S and T2D demonstrated heights significantly greater than T3 (P < 0.05) with no significant difference observed between the two varieties, suggesting that soil amendment effectively promoted the growth height of both rose varieties. In the context of T3 treatment, T3S and T3D displayed the smallest heights with no significant differences, implying that T3 did not facilitate growth in either variety. The differences in growth were particularly evident only under the T1 condition (Figure 2). Both T1 and T2 significantly enhanced the height of single-head and multi-head roses with T1 exhibiting the most pronounced impact on the height of the single-head variety. The slowest growth occurred in both varieties under T3 characterized by a lack of significant differences, while T1 emerged as the optimal treatment for increasing the height of rose plants.

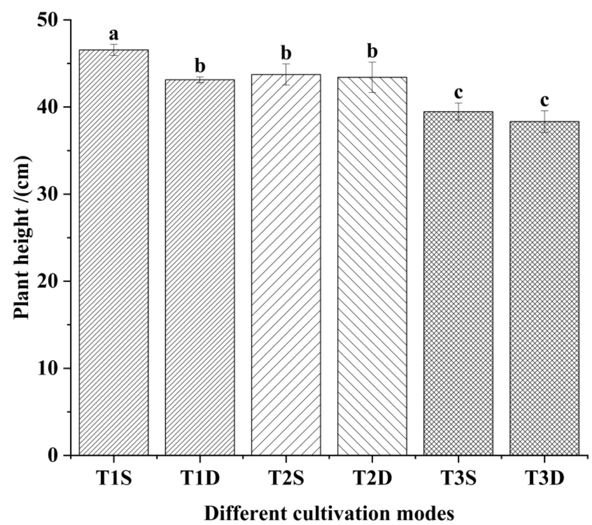

Figure 2. Effects of different cultivation modes on plant height of roses. The different lowercase letters in the same column indicated significant difference between different treatments (P < 0.05).

The influence of different cultivation modes on the stem diameter of roses

The cultivation mode exerted a significant influence on the stem diameter of rose plants (P < 0.05). The overall measurements of stem diameter across the three modes demonstrated that T1 and T2 were notably superior to T3, indicating that either T1 or T2 could substantially enhance the stem thickness of roses compared to T3. Under the T1 treatment, T1D exhibited a significantly greater stem diameter than T1S, suggesting a disparity in stem growth between the two varieties in the substrate with multi-head roses demonstrating superior stem thickness over single-head varieties. In the context of T2 treatment, both T2S and T2D showed significant differences in stem diameter compared to T1 and T3 ($P < 0.05$) with no notable difference between the two varieties, indicating that organic soil improvement effectively promoted stem growth in the plants. Conversely, under T3 treatment, both T3S and T3D recorded the smallest stem diameters with T3S being significantly lower than T3D ($P < 0.05$), highlighting the disparities in growth performance under the T3 mode (Figure 3). Overall, both T1 and T2 significantly enhanced the stem thickness of single-head and multi-head roses with T2 showing the most pronounced effects on the stem diameter of both varieties. In contrast, both varieties exhibited the smallest stem diameters under T3, characterized by significant differences. Therefore, T2 emerged as the optimal treatment for promoting stem diameter growth in roses.

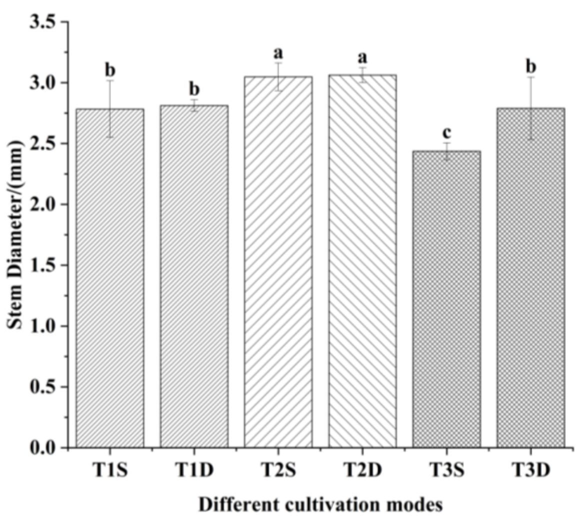

Figure 3. Effects of different cultivation modes on stem diameter of roses. The different lowercase letters in the same column indicated significant difference between different treatments ($P < 0.05$).

The influence of different cultivation modes on the number of branches in roses

The cultivation mode demonstrated a significant effect on the number of branches in rose plants ($P < 0.05$). The overall branch counts across the three modes indicated that T1 and T2 were significantly greater than T3, suggesting that either T1 or T2 could markedly enhance the branch numbers of the two rose varieties in comparison to T3. Under the T1 treatment, T1D exhibited a significantly higher number of branches than T1S, implying a notable disparity in growth conditions between the two varieties in the substrate with multi-head roses producing a significantly greater number of branches than single-head varieties. In the case of T2 treatment, there was no significant difference in branch counts between T2S and T2D, indicating a comparable level of branching in both varieties. In contrast, both T3S and T3D exhibited the lowest branch counts in the T3 treatment with no significant difference between them, highlighting that T3 did not promote branching in either variety (Figure 4). Both T1 and T2 significantly increased the number of branches in both varieties, while T3 resulted in the slowest branching rates for the two varieties, showing no significant differences. Overall, T1 emerged as the optimal choice for promoting branching in roses.

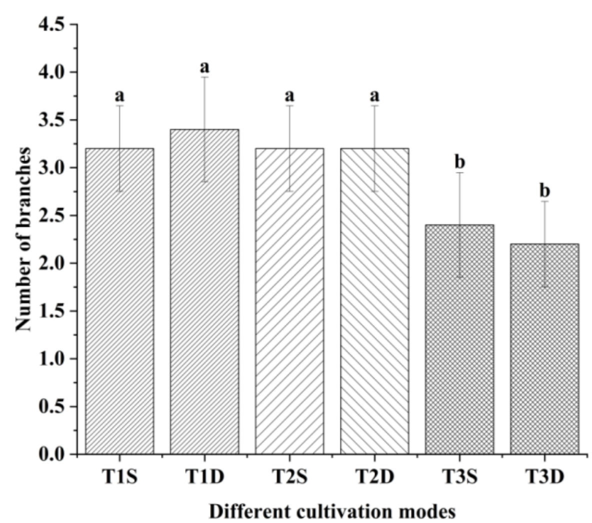

Figure 4. Effects of different cultivation modes on branch number of roses. The different lowercase letters in the same column indicated significant difference between different treatments ($P < 0.05$).

The influence of different cultivation modes on the number of leaves in roses

The results showed that the cultivation mode significantly affected the number of leaves in rose plants ($P < 0.05$). An overall assessment across the three modes revealed that T1 and T2 markedly exceeded T3 in leaf count, indicating that either T1 or T2 could significantly enhance the leaf number of both varieties compared to T3 with no notable differences observed between single-head and multi-head varieties. Under T3 treatment, both varieties exhibited the lowest leaf counts with no significant differences, suggesting that T3 did not promote leaf growth in either variety (Figure 5). Overall, both T1 and T2 were effective in significantly increasing the leaf numbers of single-head and multi-head roses with T2 demonstrating the most pronounced effect. Conversely, T3 was associated with the slowest growth rates among the varieties, showing no significant differences. Therefore, T2 stood out as the optimal choice for enhancing the leaf number in roses.

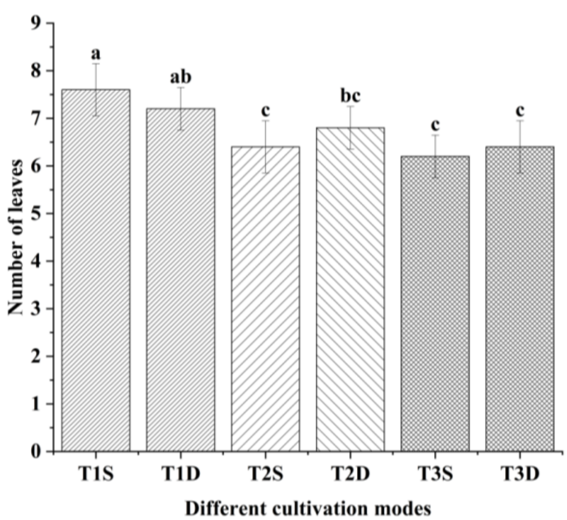

Figure 5. Effects of different cultivation modes on leaf number of Roses. The different lowercase letters in the same column indicated significant difference between different treatments ($P < 0.05$).

The influence of different cultivation modes on the SPAD value of roses

The results showed that the cultivation mode exerted a significant effect on the relative chlorophyll content represented by the SPAD value in rose leaves ($P < 0.05$). An overall analysis across the three modes indicated that the SPAD values for T2 and T1 were substantially higher than those for T3, suggesting that both T1 and T2 could notably enhance the relative chlorophyll content in rose leaves. Under the T1 treatment, there was no significant difference in SPAD values between T1S and T1D, indicating that the substrate provided a balanced enhancement of chlorophyll for both varieties. In the case of T2 treatment, T2S and T2D also showed no significant differences in SPAD values, yet both maintained a high overall level, reflecting the beneficial effect of soil amendment on chlorophyll enhancement for both varieties. Conversely, under T3 treatment, both T3S and T3D exhibited the lowest SPAD values with no significant differences, indicating that T3 was detrimental to chlorophyll synthesis and that varietal adaptability differences were not markedly apparent across the three modes (Figure 6). The results demonstrated that both T2 and T1 significantly improved the SPAD values of both single-head and multi-head roses with T2 demonstrating the most pronounced promoting effect. T3 yielded the lowest SPAD values with no significant differences between varieties, making T2 the optimal treatment for enhancing the relative chlorophyll content in rose leaves.

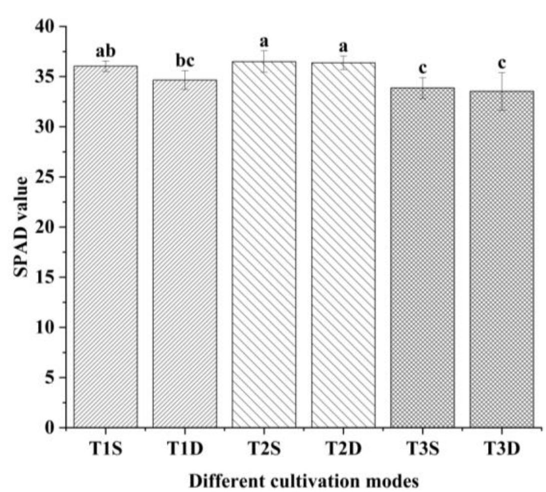

Figure 6. Effects of different cultivation modes on SPAD value of roses. The different lowercase letters in the same column indicated significant difference between different treatments ($P < 0.05$).

Table 3. Correlation analysis of growth indicators of roses under different cultivation modes.

Cultivation mode	Variety	Index	H	W	L	B	SPAD
T1	S	H	1				
		W	0.978**	1			
		L	-0.197	-0.246	1		
		B	0.899*	0.964**	-0.167	1	
		SPAD	0.054	0.122	-0.985**	0.062	1
	D	H	1				
		W	0.957*	1			
		L	0.284	0.035	1		
		B	0.946*	0.966**	0.218	1	
		SPAD	-0.004	0.162	-0.305	0.234	1
T2	S	H	1				
		W	0.156	1			
		L	0.868	0.016	1		
		B	0.700	0.632	0.408	1	
		SPAD	-0.354	-0.790	-0.485	-0.44	1
	D	H	1				
		W	0.800	1			
		L	0.573	0.631	1		
		B	0.580	0.176	0.667	1	
		SPAD	-0.007	-0.008	-0.597	-0.624	1
T3	S	H	1				
		W	0.736	1			
		L	0.786	0.434	1		
		B	0.074	0.053	-0.408	1	
		SPAD	0.903*	0.747	0.914*	-0.185	1
	D	H	1				
		W	0.156	1			
		L	0.573	0.540	1		
		B	0.008	-0.975**	-0.408	1	
		SPAD	0.273	0.989**	0.614	-0.932*	1

Note: H: plant height. W: stem diameter. L: number of leaves. B: number of branches. SPAD: relative chlorophyll content. *: $P < 0.05$. **: $P < 0.01$.

Correlation analysis of growth traits of roses under different cultivation modes

A Pearson correlation analysis was conducted on various growth traits of roses under different cultivation modes, revealing varied correlations among the indicators. For single-head roses (T1S) cultivated in substrate (T1), there was a highly significant positive correlation between plant height and stem diameter (r = 0.987, $P < 0.01$), a significant positive correlation between plant height and the number of branches (r = 0.899, $P < 0.01$), and a highly significant positive correlation between stem diameter and the number of branches (r = 0.964, $P < 0.01$). Notably, the SPAD value exhibited a highly significant negative correlation with the number of leaves (r = -0.985, $P < 0.01$). For multi-head roses (T1D) under T1, the plant height showed a significant positive correlation with stem diameter (r = 0.957, $P < 0.01$), while the number of branches correlated positively with both plant height and stem diameter (r = 0.946 and r = 0.966, $P < 0.01$), respectively. Under soil amendment cultivation (T2), no significant correlations were observed among the growth indicators for either variety. In conventional soil cultivation (T3), single-head roses (T3S) demonstrated significant positive correlations of SPAD values with both leaf number and plant height (r = 0.903 and r = 0.914, $P < 0.01$), respectively. For multi-head roses

(T3D), there was a highly significant negative correlation between the number of branches and stem diameter (r = -0.975, $P < 0.01$), while SPAD value showed a highly significant positive correlation with stem diameter (r = 0.989, $P < 0.01$) (Table 3). The results indicated that, in the T1 cultivation mode, higher plant heights for T1S roses correlated with greater stem diameters and branch numbers, while larger stem diameters corresponded to increased branch numbers. Conversely, higher SPAD values in T1S roses coincided with fewer leaves. For T1D roses, increased plant height also correlated with greater stem diameter, which in turn was associated with a higher number of branches. In the T2 cultivation mode, the two varieties did not exhibit any significant correlation among growth traits. Under the T3 cultivation mode, T3S roses displayed elevated SPAD values as leaf numbers and plant heights increase, whereas in T3D roses, an increase in branch number correlated with a decrease in stem diameter, and an increase in stem diameter was associated with lower SPAD values.

Principal component analysis and comprehensive evaluation of growth traits of roses under different cultivation modes

A principal component analysis was performed on the growth traits of roses cultivated under different modes. Two principal components were extracted from the data for each variety with a cumulative contribution of 88.32%, which accurately reflected the primary information. The eigenvalues of the components were 3.06 and 1.36, respectively. The first principal component accounted for 61.17% of the variance, primarily influencing plant height and leaf number, while the second principal component contributed 27.15%, mainly affecting stem diameter and SPAD value. A higher comprehensive score indicated better growth performance. The overall rankings for the treatments were T2S > T1S > T2D > T1D > T3S > T3D. The comprehensive scores were calculated using the weights derived from the variance contribution of the two principal components as $F = 0.61 \times PC1 + 0.27 \times PC2$. Generally, both substrate cultivation (T1) and soil amendment cultivation (T2) outperformed conventional soil cultivation (T3), promoting overall growth for both rose varieties. Within the T2 mode, T2S exhibited superior growth compared to T2D, indicating that organic fertilizer amendment was more conducive to single-head roses. In the T1 mode, T1S displayed better growth than T1D, suggesting that substrate cultivation was better suited for single-head varieties. Notably, T3 received the lowest comprehensive score and showed minimal impact on growth differences between the two varieties.

Discussion

Physical properties of cultivation substrates and disease incidence in roses

The physical properties of cultivation substrates are critical factors influencing plant growth [19], as they directly determine the aeration, water retention, and nutrient-holding capacity of the root environment, subsequently impacting physiological metabolism [20]. Substrate compaction can have an impact with excessively high bulk density leading to poor aeration and restricted root development, while optimal conditions favor root respiration and nutrient uptake [21]. Previous research indicated a negative correlation between substrate bulk density and root vitality as well as dry matter weight. Reducing bulk density could enhance root absorption efficiency [22]. Yang *et al*. discovered that deep plowing combined with fertilization using chemical and organic materials significantly reduced soil bulk density in the 0 - 45 cm layer, which aligned with the results of this study [23]. Total porosity, aeration pores, and water-holding pores are indices for evaluating the balanced capabilities of the substrate in terms of aeration and water retention [24]. The differences in physical properties of the substrate were also associated with rose disease incidence. The rate of diseased plants and the disease index in T3 were significantly higher than that in T1 and T2 with T2 showing the lowest rates, which was consistent with the findings of Zhao *et al*. that the loose structure in T1 facilitated root respiration and enhanced disease resistance [7], while T2 benefited from beneficial microorganisms in the biological organic fertilizer such as humic acid-decomposing bacteria and actinomycetes that suppressed pathogens [25]. Organic fertilizer also enhanced the plant's immune response [26]. Conversely, T3's compacted soil characterized by poor aeration led to weak root vitality and low resistance, making it more susceptible to pests and diseases.

Analysis of growth traits and overall rankings of roses

The growth traits of plants encapsulate their adaptability to environmental conditions. This study evaluated survival rate, plant height, stem diameter, branch number, leaf count, and SPAD value to analyze the effects of different cultivation modes on the growth characteristics of roses. In terms of survival rate, T1 and T2 exhibited markedly higher figures compared to T3 with T2S achieving the highest survival rate. The survival rate of multi-head roses in T1D was slightly superior to that of T1S, suggesting that the application of biological organic fertilizers had a more pronounced effect in promoting the survival of single-head roses. For growth indicators such as height and stem diameter, T1S recorded the tallest plants, while T2 produced the stoutest stems across both varieties, which reflected that T1's superior water retention benefited vertical growth, while T2's organic fertilizers provided a slow release of nutrients conducive to stem thickening. Zeng *et al*. confirmed that the combination of biological organic fertilizers and chemical fertilizers could enhance the height and stem diameter of cut roses [27]. Conversely, T3 exhibited the lowest height and stem diameter, validating the suppressive effects of poor soil structure. The number of branches and leaves significantly affects ornamental quality and photosynthetic efficiency. In T1, T1D had the highest branch count, while T2 recorded the highest leaf numbers across both varieties. The differences in branch number were linked to varietal traits and substrate nutrient levels, while the increase in leaf count correlated with the overall nutrition provided by organic fertilizers. T3 had the fewest branches and leaves, reflecting a dual limitation of nutritional deficiency and environmental stress. The SPAD values of both varieties under T2 were significantly higher related to the presence of mineral elements such as magnesium, a component of chlorophyll in the organic fertilizers, which was consistent with previous reports that biological organic fertilizers could enhance the availability of essential mineral elements in the soil and promote chlorophyll synthesis in crops [28]. Correlation analysis of growth traits under different cultivation modes revealed that plant height significantly correlated with stem diameter in T1, and stem diameter correlated positively with branch number, indicating that plant growth in a loose substrate fostered both vertical and lateral development, potentially due to high nutrient absorption efficiency [29]. Conversely, SPAD values were found to correlate negatively with leaf count, likely due to nutrient competition arising from excessive leaf density, which was similar to findings by Li *et al*. who demonstrated a significant negative correlation between leaf SPAD values and seeding rates prior to heading in direct-seeded early rice [30]. In T1D, both height and stem diameter exhibited significant positive correlations with branch number, aligning with the results from Wen *et al*. and Yi *et al*. [31, 32]. In T2, no significant correlations were observed among the growth indicators. In T3, the SPAD value of single-head roses correlated positively with both height and leaf count, indicating interdependence between chlorophyll synthesis and plant growth under nutrient-scarce conditions. The branch number in T3D showed a significant negative correlation with stem diameter [32], which contrasted with previous studies and might be attributed to varietal responses to environmental conditions. The principal component analysis results showed that the T2S treatment exhibited the best overall growth performance when evaluating different cultivation methods due to its advantages in survival rate, stem diameter, leaf number, and SPAD value followed by the T1S treatment, which performed well in plant height and branching number, while the T3 treatment scored the lowest, confirming the impact of environmental limitations on rose growth.

Conclusion

The results of this study demonstrated that both substrate cultivation (T1) and soil amendment cultivation (T2) significantly enhanced the growth traits of cut roses by improving the physical properties of the medium, optimizing nutrient supply, and increasing plant resilience. The overall effectiveness of T2 proved to be superior. The practical implications of these findings suggested that, in large-scale floral production, prioritizing the cultivation mode that employed biological organic fertilizers for soil improvement was advisable, particularly for single head rose varieties, to enhance yield and quality. Both biological organic fertilizer-based soil improvement cultivation and substrate cultivation effectively addressed the shortcomings of traditional soil cultivation. Among these, biological organic fertilizer-based soil improvement stood out due to its comprehensive advantages, positioning it as a promising mainstream method for large-scale production of cut roses in the future, thereby providing crucial technical support for the sustainable development of the floral industry.

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References

1. Zhang SY, Meng J, Han Yl, Wu HZ. 2019. Isolation and identification of the pathogen causing gray mold on roses in Yunnan Province. J Zhejiang Univ. 45(6):692-698.
2. Li YQ, Han Q, Wang ZF, Cui JP, Zhao SW, Zhao HE. 2013. Evaluation of hybrid compatibility between wild roses and cultivated roses. Jiangsu Agric Sci. 41(6):155-160.
3. Xiong ZY, Yu R, Hu ZY, Zhang YM, Liu QL. 2023. Research progress on morphogenesis and flowering regulation in roses. J Agric Sci Technol. 25(2):68-75.
4. Zhang JY, Liu C, Wang WZ, Yang SN, Yang SX, Zhang JK, *et al*. 2019. Analysis of growth rule of cut rose for year-round flower shoot production. J South Agric. 50(8):1801-1806.
5. Sun JG, Wang CJ, Chen ZG, Li JL, Sun GW, Yu J, *et al*. 2016. The progress about continuous cropping obstacles of flue-cured tobacco. HJ Agric Sci. 6(6):218-213.
6. Wu HT, Wei M, Yang FJ, Wang XF. 2008. Improvement effects of rotation and fallow on continuous cropping soil of cucumber in solar greenhouse. Shandong Agric Sci. 2008(5):59-63.
7. Zhao AX, Qu SP, Su Y, Wang LH, Zhang LF, Yang XM, *et al*. 2018. Growth status and quality analysis of cut roses under different cultivation modes. JSUMSE. 40(11):10-19.
8. Xiong Q, Mo HK, Jiang NF, H PL. 2016. Comparative experiment on soilless substrate cultivation and soil cultivation of vegetables in intelligent multi-span greenhouse. S Hort. 27(4):13-14.
9. Liu ZL, Gao X, Zhang YY, Gu RY, Jiao J, Gao JJ, *et al*. 2020. Comparative study on quality and yield of tomato between substrate culture and soil culture. Jiangsu Agric Sci. 48(1):124-127.
10. Liu XH, Dai SL. 2004. Preliminary study on the test of soilless culture substrates for chrysanthemum. HNU Sci Technol. 2004(1):23-26.
11. Huang ZB, Hao WJ, Feng ZS, Kong LJ, Ma Q, Zha OP. 2022. Application status and research prospects of humic acid in soil improvement and pollution remediation. Bull Soil Water Conserv. 42(2):354-361, 376.
12. Liu M, Cholidah L, Ma SM, Ma Q, Song WF, Shen MZ, *et al*. 2022. Biochar combined with organic and inorganic fertilizers promoted the rapeseed nutrient uptake and improved the purple soil quality. FNUT. 9:997151-997151.
13. Ahmad I, Ali S, Khan KSK, Hassan F, Shakeel A. 2015. Use of coal derived humic acid as soil conditioner for soil physical properties and its impact on wheat crop yield. IJB. 2015(12):81-89.
14. Zhang QQ, Fu ZP, Qi LL, Liu Z, Wei Q, Liang H, *et al*. 2023. Effects of bio-organic fertilizer on yield, quality of facility tomato and soil physicochemical properties. Fertil Health. 50(5):23-28, 76.

15. Su GJ, Lou L, Li D, He LH, Wang JW, Shen JG, *et al*. 2023. Effects of base application rate of bio-organic fertilizer on yield of greenhouse pakchoi and soil nutrient content. J Agric. 13(7):44-47.
16. Yu M, Gao XM, Liu XH, Wang ZX. 2022. Effects of straw returning amount on soil nutrients and bacterial community structure in dryland. J Arid Land Resour Environ. 36(3):171-177.
17. Jing Y, Zhang ZG. 2002. "One-stop" method for determining common physical and chemical properties of cultivation substrates. N Hortic. 2002(3):18-19.
18. Cao TT, Liu C, Fan YW, Ma L, Ren ZY, Yuan ZX, *et al*. 2024. Effects of different nitrogen supply levels on the growth and development of mini potted roses. J Agric Sci Technol. 26(2):67-79.
19. Choi P, Jong M. 2014. Development of root media containing pine bark for cultivation of horticultural crops. Kor J Hort Sci Technol. 32(4):499-506.
20. Tang ZW, Zhou WT, Wang BR, Zhong KY, Xiong R, Long P, *et al*. 2021. Effects of ridge-furrow cultivation on root characteristics and soil physical properties of rice. J Ecol. 40(12):3961-3969.
21. Hu HZ, Hu BY, Zhang XL, Liu ZC, Liu JY, Ci E. 2020. Effects of no-tillage duration and tillage frequency on soil bulk density and rice growth in paddy fields. Chin Agric Sci Bull. 36(10):1-7.
22. Sun Y, Wang YQ, Feng JY, Wang Y, Yang M, Xu L. 2006. Effects of soil compaction stress on cucumber growth, yield and nutrient uptake. J Plant Nutr Fert. 2006(4):559-564.
23. Yang JY, Gu SY, Li YH, He WY, Tang Y, Zhai C, *et al*. 2021. Effects of deep plowing-rotary tillage rotation and organic fertilizer application on soil physical properties of black soil farmland. Chin J Soil Sci. 52(6):1290-1298.
24. Boodt MD, Verdonck O. 1972. The physical properties of the substrates in horticulture. ISHS. 8(3):37-44.
25. Fu LJ, Zhang AM, Wang XD, Zhou GS. 2017. Research progress on bio-organic fertilizer improving facility vegetable soil. Soil Fert Sci China. 2017(3):1-5.
26. Akanmua AO, Olowe OM, Phiri A, Nirere D, Odebode A, Karemera NJ, *et al*. 2020. Organic farming: Exploration of organic amendments and bioagents for sustainable agriculture. GJAR. 8(3):59-74.
27. Zeng M, Pan Y, Peng Y, Dab XLT. 2021. Effects of reduced chemical fertilizer combined with charcoal-based organic fertilizer on the growth of cut roses and soil properties in facilities. J South Agric. 52(8):2202-2210.
28. Liu ZK, Liu CP, Yang HX, Meng FZ, Wang YJ, Yang LY, *et al*. 2025. Effects of bio-organic fertilizer on maize growth and soil properties in sandy tidal soil. Henan Agric Univ. 59(2):295-305.
29. Liu WB, Cui SY, Wu LT, Qi WL, Chen J, Ye ZQ, *et al*. 2023. Effects of bio-organic fertilizer on soil fertility, yield, and quality of tea. J Soil Plant Nut. 23(4):5109-5121.
30. Li MY, Cheng G, Shi QH, Pan XH, Tian XM. 2010. Effects of seeding rate on population quality and yield of direct-seeded early rice. Acta Agric Univ Jiangxiensis. 32(3):419-424.
31. Wen L, Chen JQ, Dai ZG, Gong YC, Liu Q, Li N, *et al*. 2013. Multiple regression and partial correlation analysis on leaf yield of *Corchorus olitorius* L. using R language. Crop J. 2013(1):49-53.
32. Yi LX, Sa RL, Fan X, Zhao C, Li R, Siqin BT. 2022. Variation analysis of main quality and agronomic traits of oil flax. J Agric Sci Technol. 24(5):56-67.