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Article

Nutrient management in potted Syngoniums using water soluble fertilizers and biofertilizers: effects on growth and soil fertility

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Abstract

The global ornamental plant market has been providing economic stability to nations for decades. To achieve enhanced productivity of ornamental plants, it is necessary to develop effective nutrient management techniques. A 2-year study was conducted to develop efficient nutrient management protocols for Syngonium (*Syngonium podophyllum* Schott.), a high-value, commercial-potential plant. The experiments were conducted in a completely randomized design with 11 nutrient management treatments, comprising different doses of water soluble fertilizer (WSF) alone or in combination with arbuscular mycorrhizal fungi (AMF) or phosphorus solubilizing biofertilizer (PSB), and these treatments were compared with commercial fertilizer as well as control. The results revealed that the integrated use of WSF with its higher dose (4 g kg^{-1} soil) and PSB (200 mg kg^{-1} soil) application significantly improved the plant height and the plant spread by 10.4%–25.2% and 5.7%–12.6%, respectively. Furthermore, the soil fertility and nutrient concentration in the leaves were also observed to be significantly improved due to the combined application of WSF and PSB. Likewise, the maximum leaf fresh (257.5 g) and dry weight (36.1 g) were recorded in treatment with WSF 4 g + PSB. However, WSF in conjunction with AMF resulted in the highest root fresh and dry weight over other nutrient combinations. In conclusion, it was found that for better foliage and root growth of Syngonium with improved soil fertility and plant nutrient content, integrated application of WSF with either PSB and (or) AMF is suitable.

Key words: arbuscular mycorrhizal fungi, phosphorus solubilizing biofertilizers, root and shoot growth, soil nutrient status, water soluble fertilizer

Résumé

Depuis des décennies, le marché mondial des plantes ornementales s'avère économiquement stable à l'échelle nationale. Accroître le rendement des plantes ornementales n'est réalisable que par l'élaboration de techniques qui gèreront efficacement l'apport de nutriments. Dans cette optique, les auteurs ont entrepris une étude de deux ans afin de mettre au point un protocole efficace pour gérer l'apport d'éléments nutritifs au syngonium à feuilles pédicellées (*Syngonium podophyllum* Schott.), plante de grande valeur à potentiel commercial. Les expériences suivaient un dispositif en blocs randomisés et ont porté sur onze programmes de nutrition, soit l'application de différentes doses d'engrais hydrosoluble combinée ou pas à des champignons mycorhiziens à arbuscules ou à un engrais biologique solubilisant le phosphore. Ces traitements ont été comparés à l'application d'un engrais commercial et à un témoin. Selon les résultats, l'application de l'engrais hydrosoluble à sa plus forte concentration (4 g par kg de sol) et de l'engrais biologique (200 mg par kg de sol) améliore nettement la taille de la plante et son étalement, soit de 10,4 à 25,2 % et de 5,7 à 12,6 %, respectivement. Les auteurs ont aussi noté que l'application des deux engrais améliore significativement la fertilité du sol et la concentration de nutriments dans les feuilles. L'application de 4 g d'engrais hydrosoluble et de l'engrais biologique a engendré le poids frais (257,5 g) et le poids sec (36,1 g) les plus élevés pour les feuilles. Toutefois, c'est la combinaison engrais hydrosoluble et champignon mycorhizien qui a donné lieu au poids frais et au poids sec les plus élevés pour les racines. Les auteurs en concluent que, pour obtenir le plus beau feuillage et la meilleure croissance des racines du syngonium avec un sol plus fertile et une teneur en éléments nutritifs supérieure chez la plante, on peut appliquer un engrais hydrosoluble avec un engrais biologique solubilisant le phosphore ou un champignon mycorhizien à arbuscules. [Traduit par la Rédaction]

Mots-clés : champignon mycorhizien à arbuscules, engrais biologique solubilisant le phosphore, croissance des racines et des pousses, bilan nutritif du sol, engrais hydrosoluble

Introduction

Syngonium (*Syngonium podophyllum* Schott.) is a popular houseplant from the Araceae family that is generally grown across the world because of its attractive ornamental foliage. The appealing nature of the flora makes it a potential merchandizable plant in the global market. Moreover, to maximize the profits from the crop, the introduction of Syngonium-specific nutrient management techniques is a must. Although Syngonium is a plant originating from southern Mexico, farmers from Asian and African countries have developed interest in the cultivation and sale of the plant on a global platform (Chen et al. 2002; Dhanasekaran et al. 2020).

The plant, due to its easy propagation, hardiness, low maintenance, and multiple uses in interior settings, including hanging baskets, ground cover, climber, or as a small shrub, carries enormous commercial potential (Chen et al. 2002). The supply of essential plant nutrients in an optimum proportion is vital for better plant growth, development, and nutrient-use efficiency (Ruxanabi et al. 2020). Thus, fertilizers play a pivotal role and act as critical input for the optimum growth and production; however, there seems to be a scarcity of systematic information on nutrient management protocols for many indoor plants, including Syngonium, in the literature (Malhotra 2016).

Among major options for nutrient management, water soluble fertilizers (WSF), multi-nutrient fertilizers, biofertilizers, organic manures, plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF)-controlled release fertilizers, etc., are important (Meena et al. 2014; Ranva et al. 2019; Bana et al. 2021). Due to unstable yields and quality in most ornamental crops, higher fertilizer cost is a major concern as economic returns are not much remunerative in the long run. Therefore, it becomes obligatory to augment fertilizer-use efficiency while ensuring better growth, yield, and quality. Out of the essential nutrients, nitrogen (N), phosphorus (P), and potassium (K) are of the utmost importance and are required in greater proportions. N controls the physiological and biochemical processes regulating the synthesis of proteins (Bamboriya et al. 2017), chlorophyll production, and foliage growth (Bana et al. 2012).

Similarly, P is a requisite for photosynthesis and imparts the energy transfer mechanism within the plant system. It is linked to overall vigor and is required at the highest levels during the early stages of ontogeny (Jahish et al. 2017). In a similar manner, K is responsible for cell division, cell enlargement, and synthesis as well as movement of sugars and starches in the plant system. It also increases foliage chlorophyll levels and regulates stomata closing and opening in plant leaves (Ruxanabi et al. 2020). K is well known to improve the quality of produce and is required throughout the life cycle of plants (Malhotra 2016).

Usage of WSF in diverse crops minimizes ∼30%–50% of fertilizer requirements, in addition to reducing irrigation water consumption (Shirgure and Srivastava 2015; Malhotra 2016). Due to their instant solubility and easy application, the WSF are gaining popularity in high-tech irrigation systems and as a foliar spray for augmenting the growth in short time span. Although these fertilizers leach out of the soil easily (Bana 2009), but owing to low salt index, their application is reasonably safer for foliage plants (Malhotra 2016). Furthermore, a precise amount of nutrient demands can be met using WSF, either as foliar applications or in pressurized irrigation. In existing studies, generally, the rate of WSF is used at 1% solution as foliar application (Dhanasekaran et al. 2020); however, no systematic information is available on the dosage for soil nutrition in Syngonium.

During recent decades, in addition to fertilizers, the use of biofertilizers has emerged as a cost-effective and environmental-friendly component of nutrient management strategies in fields as well as horticultural crops (Yadav and Kavita 2016). Besides plant biomass augmentation (∼20%–30%), biofertilizers also lower the necessity of chemical nutrient sources by up to 20%–25% (Khan et al. 2009; Bana et al. 2012). Furthermore, usage of biofertilizers leads to improved microbial activity, biomass production, and nutrient-use efficiency without significant enhancement in production cost (Liu et al. 2009; Ruxanabi et al. 2020). Hence, it becomes imperative to use biofertilizers as an integral element of sustainable soil fertility management modules. Among various biofertilizers, AMF and phosphorus solubilizing biofertilizer (PSB) are two important inoculants that have not been explored much as a constituent of nutrient management schedules of various ornamental crops. Although P is abundant in soils, its availability is restricted to plants due to fixation in soils (Pradhan and Sukla 2005; Babazoi et al. 2019). Thus, the release of fixed and insoluble P into soluble form is crucial in augmenting availability of P to the plants (Chandler et al. 2008; Jahish et al. 2017). Soil microorganisms play a key role in soil P dynamics and its subsequent availability to plants (Khosro 2012). The PSB in soil releases numerous acids that solubilize the fixed and insoluble P into the plant available soluble form, thereby promoting plant growth (Pradhan and Sukla 2005).

Likewise, AMF are known as the most ancient and widespread symbionts. AMF symbiosis is a mutualistic relationship formed between fungi and living roots of higher plants (Das et al. 2017). Such rhizospheric association yields multiple benefits to the host plant species (Das et al. 2018), including enhancement of growth and biomass of host plants, mitigating various plant stresses, and enhancing water-use efficiency (Pal et al. 2018). AMF expand the rhizospheric area of the plant system from 10 to 1000 times through their ramifying hyphae, leading to an increase in their surface area for harnessing P, other nutrients, and water (Harrier and Watson 2003; Arumugam et al. 2010; Pal et al. 2018).

So far, no scientific information is available on the effects of WSF and biofertilizer application (PSB as well as AMF) in combination or alone on Syngonium. Likewise, the optimum fertilizer dose for better growth in Syngonium is yet to be worked out. Studies on fertilizer application effects on Syngonium leaf nutrient content and the resultant soil fertility are also not available. Considering the knowledge gaps, the present study was conducted to develop nutrient management protocols in Syngonium potted plants and to test the efficacy of AMF and PSB with WSF for improving the growth and development of Syngonium.

Materials and methods

Location and the soil medium details

The experiment was conducted for two consecutive years during 2018–19 and 2019–20 at the Glasshouse Complex of Division of Floriculture and Landscaping, ICAR–Indian Agricultural Research Institute, New Delhi. The soil medium used for filling the pots was typic haplustepts with sandy loam texture. The organic carbon and available N of the media were low, and available phosphorus (P) and available potassium (K) were medium, with a nearly neutral pH (Table 1). Before the initiation of experimentation, the DTPA-extractable Zn, Fe, Mn, and Cu contents of the media were also analyzed.

Treatment details

The rooted plants of Syngonium were planted in pots of size 25.4 cm and after planting, the plants were watered lightly. Once the plants were established, a full dose of commercial fertilizer (CRF) formulation and biofertilizers, namely AMF and PSB, was applied as per treatments. Initially, half dose of WSF with $N:P_2O_5:K_2O$ (19:19:19) content was applied 1 week after the application of AMF or PSB, and the second dose was applied 2 months after the first dose. The AMF and PSB were mixed in the soil medium during pot-filling stage. Uniform and healthy plants were maintained for all the treatments and followed the recommended cultural practices.

The experiment of 11 treatments was replicated thrice, with five pots in each replica. The treatments comprised different doses of WSF alone or in combination with AMF or PSB, and these treatments were compared with CRF as well as the control (no fertilizer). The AMF and PSB were procured from the Division of Microbiology, ICAR–Indian Agriculture Research Institute, New Delhi. AMF and PSB used in the present experiment belonged to *Glomus mosseae* and *Bacillus polymyxa*, respectively. As determined by the method suggested by Gaur and Adholeya (1994), the AMF spore count was 29–31 per g and the cell count in the PSB culture was 10^8 per g. The details of the treatments are given in Table 2.

Plant growth observations

Data on various growth and physiological traits, viz., plant height, plant spread, number of leaves (starting from July 2018, at an interval of 1 month and expressed as percent increase over initial data), petiole length, leaf area, and biomass (fresh and dry weight of leaves, stem, and shoot), were recorded. At the end of the experiment, roots were gently separated from the soil and washed thoroughly with water to remove excess soil. Root samples (after 150 days of planting) were examined for root weight, root diameter, root length, root surface area, and root volume using a flatbed scanner (EPSON Expression 11000XL 1.8 V3.49). Relative water content (RWC), which indicates the moisture status of plants, was determined by sampling five leaves after 150 days of planting (end of the trial) from different plants in each pot, which were brought to laboratory in tightly closed polythene bags, and then fresh weights were recorded. Later, these leaves were chopped into 0.5 cm pieces and saturated in distilled water overnight in Petri plates. Next day, the saturated leaves were taken out and nominally dried between the folds of a filter paper followed by recording of their turgid weight. The same were then transferred to an oven for 72 h after which their weight was taken. The RWC was computed from the fresh weight, turgid weight, and oven dry weight according to the Bars and Weatherly (1962) method:

$$\mathrm{RWC}\,(\%) = [(\mathrm{FW} - \mathrm{DW}) \div (\mathrm{FTW} - \mathrm{DW})] \times 100$$

where FW, DW, and FTW refer to the fresh weight, oven dry weight, and fully turgid weight of leaves, respectively.

Soil parameters

Soil samples were collected 3 months after planting to analyze pH, EC, organic carbon, available N, available P, and available K. Soil pH and electrical conductivity (EC) of the soil:water ratio of 1:2.5 (*w*/*v*) were determined using a glass electrode pH meter and EC meter, respectively (McLean 1982). Organic carbon was determined by the method outlined by Walkley and Black (1934). Soil samples were analyzed for studying available N, P, and K through modified Kjeldahl's method (Jackson 1973), Olsen's method (Olsen et al. 1954), and flame photometer method (Jackson 1973), respectively. Before initiation of experiments, the extractable Zn, Mn, Fe, and Cu were determined in soil samples using DTPA (Lindsay and Norvell 1978).

Nutrient analyses in plants

Leaf samples were collected in paper bags and brought to the laboratory for analysis. Samples were washed with distilled water, dried in shade, and then ground to fine powder. The ground samples were digested with di-acid ($HNO_3:HClO_4$, 9:4 ratio) on a hot plate till white fumes, (color less) and the final volume was made to 100 mL with distilled water, stored in clean plastic bottles, and analyzed for N, P, K, and Ca contents (Rana et al. 2014). Leaf N contents were determined by the modified Kjeldahl method. Vanadomolybdophosphoric acid yellow color method was used for P content determination. For estimation of K and Ca concentrations in Syngonium leaves, the flame photometer method was used.

Table 1. Initial properties of media used for planting of Syngonium.

Particulars	Content	Method of analysis
1. Soil organic carbon (%)	0.46	Walkley and Black method (Walkley and Black 1934)
2. Available N (kg ha^{-1})	207.3	Modified Kjeldahl's method (Jackson 1973)
3. Available P (kg ha^{-1})	24.1	Olsen's method (Olsen et al. 1954)
4. Available K (kg ha^{-1})	142.5	Flame photometer method (Jackson 1973)
5. pH (1:2.5 soil:water)	7.1	Blackman's Xeromatic pH meter (Jackson 1973)
6. EC (dS m^{-1} at 25 °C)	0.33	Jackson (Jackson 1973)
7. DTPA-extractable Zn (mg kg^{-1})	0.63	Lindsay and Norvell (1978)
8. DTPA-extractable Fe (mg kg^{-1})	4.66	
9. DTPA-extractable Mn (mg kg^{-1})	5.32	
10. DTPA-extractable Cu (mg kg^{-1})	1.81	

Table 2. Details of treatments applied to the Synogonium samples.

S. no.	Treatment short form	Treatment description
T1	CRF	Commercial fertilizer (CRF) at 2 g kg^{-1} media
T2	WSF1	Water soluble fertilizer (WSF; 19:19:19) at 1 g kg^{-1} media
T3	WSF2	WSF at 2 g kg^{-1} media
T4	WSF4	WSF at 4 g kg^{-1} media
T5	WSF1 + AMF	WSF at 1 g kg^{-1} + AMF (arbuscular mycorrhizal fungi) at 1.5 g kg^{-1} media
T6	WSF2 + AMF	WSF at 2 g kg^{-1} + AMF at 1.5 g kg^{-1} media
T7	WSF4 + AMF	WSF at 4 g kg^{-1} + AMF at 1.5 g kg^{-1} media
T8	WSF1 + PSB	WSF at 1 g kg^{-1} + phosphorus solublizing bacteria (PSB) at 200 mg kg^{-1} media
T9	WSF2 + PSB	WSF at 2 g kg^{-1} + PSB at 200 mg kg^{-1} media
T10	WSF4 + PSB	WSF at 4 g kg^{-1} + PSB at 200 mg kg^{-1} media
T11	Control	No fertilizer control

Statistical analysis

All the data obtained from the experiment conducted under a completely randomized design were statistically analyzed using the *F* test as per the procedure given by Gomez and Gomez (1984). LSD values at $P = 0.05$ were used to determine the significance of the differences between the treatment means. Tukey's Honestly Significant Difference (HSD) test was used wherever analysis of variance (ANOVA) was significant.

Results

Growth parameters and RWC

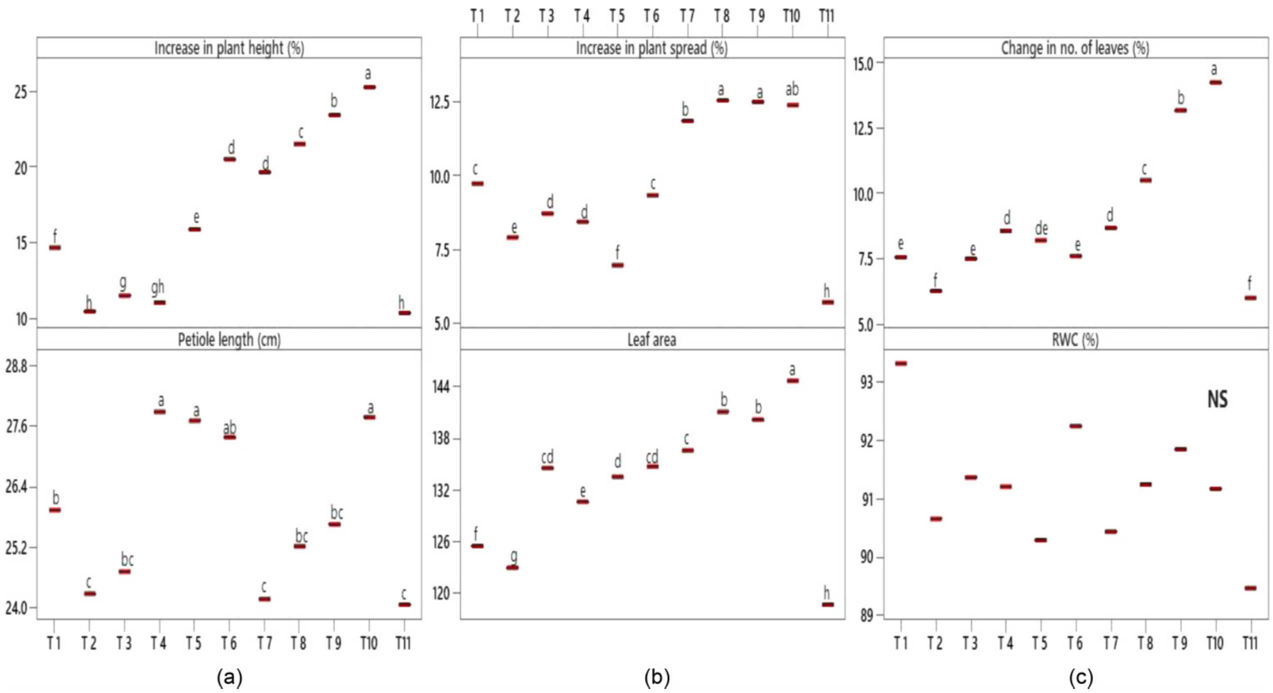
Pooled data of 2 years on plant height indicated that application of various nutrient sources enhanced the plant height by 10.4%–25.2% (Fig. 1*a*). The highest increase in plant height (25.2%) was recorded under treatment T_{10} (WSF at 4 g + PSB) followed by $T_9 > T_8 > T_6 = T_7$. The minimum % increase in plant height was observed under the control (10.4%). Furthermore, the petiole length of Syngonium plants (Fig. 1*a*) also improved significantly ($P < 0.05$) owing to nutrient application, and the maximum petiole length was noticed with a higher dose of WSF 4 g kg^{-1}(T_4), which was statistically similar to the treatments T_5, T_6, and T_{10}. However, the minimum petiole length was recorded in treatment T_{11} (control), but it was statistically similar to T_2, T_3, T_7, and T_8.

In a similar manner, the increase in plant spread ranged from 5.7% to 12.6%, and the maximum increase in plant spread (12.6%) was recorded with treatment T_8 (WSF 2 g + PSB), which was at par with treatments T_9 and T_{10}, while a minimum increase in plant spread (5.7%) was observed under the control treatment (Fig. 1*b*). The maximum number of leaves was recorded in treatment T_{10} (WSF 4 g + PSB), which was found to be significantly higher than the other treatments, whereas the minimum number of leaves was recorded in the control treatment (Fig. 1*c*). Leaf area was found to be maximum in plants supplemented with 4 g WSF and also inoculated with PSB (T_{10}), which was superior over all the other treatments. The minimum leaf area (118.7 cm^2) was recorded under the control treatment. The data related to RWC varied from 89.5% to 93.3%. However, no significant difference was observed with respect to the different treatments (Fig. 1*c*).

Root growth

Analysis of root parameters (Fig. 2) revealed that the maximum root diameter (1.81 mm) was recorded in T_{10} (WSF 4 g + PSB), which was statistically at par with T_5, T_8, and T_9 (Supplementary Fig. S1), whereas the minimum root diameter (0.96 mm) was observed in the control (T_{11}) treatment, which was statistically at par with T_1 and T_2 (Fig. 2*a*). However, the maximum root length was recorded in treatment T_9 (WSF 2 g + PSB), which was statistically similar to the treatments T_5, T_6, T_7, T_8, and T_{10}, whereas the minimum root

Fig. 1. Influence of diverse nutrient management options on growth parameters and relative water content of Syngonium plants: (*a*) plant height and petiole length, (*b*) plant spread and leaf area, and (*c*) number of leaves and RWC. The *x*-axis represents the treatment numbers; means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Tukey's HSD test; NS = nonsignificant. T1, CRF; T2, water soluble fertilizer (WSF) 1 g; T3, WSF 2 g; T4, WSF 4 g; T5, WSF 1 g + AMF; T6, WSF 2 g + AMF; T7, WSF 4 g + AMF; T8, WSF 1 g + PSB; T9, WSF 2 g + PSB; T10, WSF 4 g + PSB; T11, control.



length was observed in the control (Fig. 2*b*). The root surface area was found to be maximum under T_{10}, which was statistically greater than rest of the treatment combinations. Similar to root diameter and surface area, maximum root volume was recorded in T_{10} (WSF 4 g + PSB), and it was statistically similar to T_9, while minimum root volume was recorded in the control (T_{11}).

Biomass accumulation in different plant parts

A significant difference was found in plant biomass accumulation due to application of various treatments (Fig. 3 and Table 3). The maximum fresh and dry leaf weights were recorded in treatment T_{10} (WSF 4 g + PSB), which was statistically similar to T_6 and T_7, whereas the lowest leaf weight (both fresh and dry) was noted under the control. The maximum stem and shoot fresh weights were also found in T_{10} and it remained at par with T_7. Almost identical trends were observed in the dry weight of stems and shoots (Fig. 3).

Analysis of root biomass parameters revealed that the highest fresh and dry weights of root were found in plants supplemented with 2 g WSF and PSB (T_9), which was statistically at par with T_{10}, while the minimum root weight was observed under the control (Fig. 3*b* and Table 3). Root:shoot ratio (RSR) on fresh weight basis showed that the maximum RSR was obtained in treatment T_7 and was statistically similar to that in T_8, whereas the minimum RSR was observed under the control (T_{11}).

Nutrient concentration in leaves

Perusal of data with respect to leaf nutrient concentration indicated that the maximum leaf N content (0.27%) was recorded in treatments T_4, T_7, and T_{10} and was statistically at par with T_9; however, the minimum N concentration was recorded in the control, which was at par with T_1 (Fig. 4). Application of biofertilizers along with WSF did not produce any significant effect on leaf P concentration in Syngonium (Fig. 4). The maximum leaf K content was recorded in T_{10}, which was significantly superior to all the treatments, while the minimum K content was recorded with commercial fertilizer formulation and was at par with T_2, T_3, T_5, and T_{11}. The calcium content in leaves was found to be maximum in T_7 (WSF 4 g + AMF) and it remained on par with T_5 and T_6, whereas the minimum calcium was recorded with 2 g WSF + AMF (T_9).

Physico-chemical properties of media

The data presented in Table 4 illustrate that the maximum pH of potting media was recorded in CRF (T_1) and the minimum in the control (T_{11}). On the other hand, the maximum EC was noted in T_4, while the minimum EC value was observed under T_{11} and T_1. Furthermore, the highest available N content was observed under treatment T_{10} and it remained statistically similar to T_9 and T_7, while the minimum available N was found under the control treatment (T_{11}). Moreover, the highest available P was noted with T_9 and was statistically identical to T_{10}, while the minimum P content was found under the control and was at par with T_1. The available

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Fig. 2. Influence of diverse nutrient management options on root growth parameters of Syngonium plants. Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Tukey's HSD test. T1, CRF; T2, water soluble fertilizer (WSF) 1 g; T3, WSF 2 g; T4, WSF 4 g; T5, WSF 1 g + AMF; T6, WSF 2 g + AMF; T7, WSF 4 g + AMF; T8, WSF 1 g + PSB; T9, WSF 2 g + PSB; T10, WSF 4 g + PSB; T11, control.

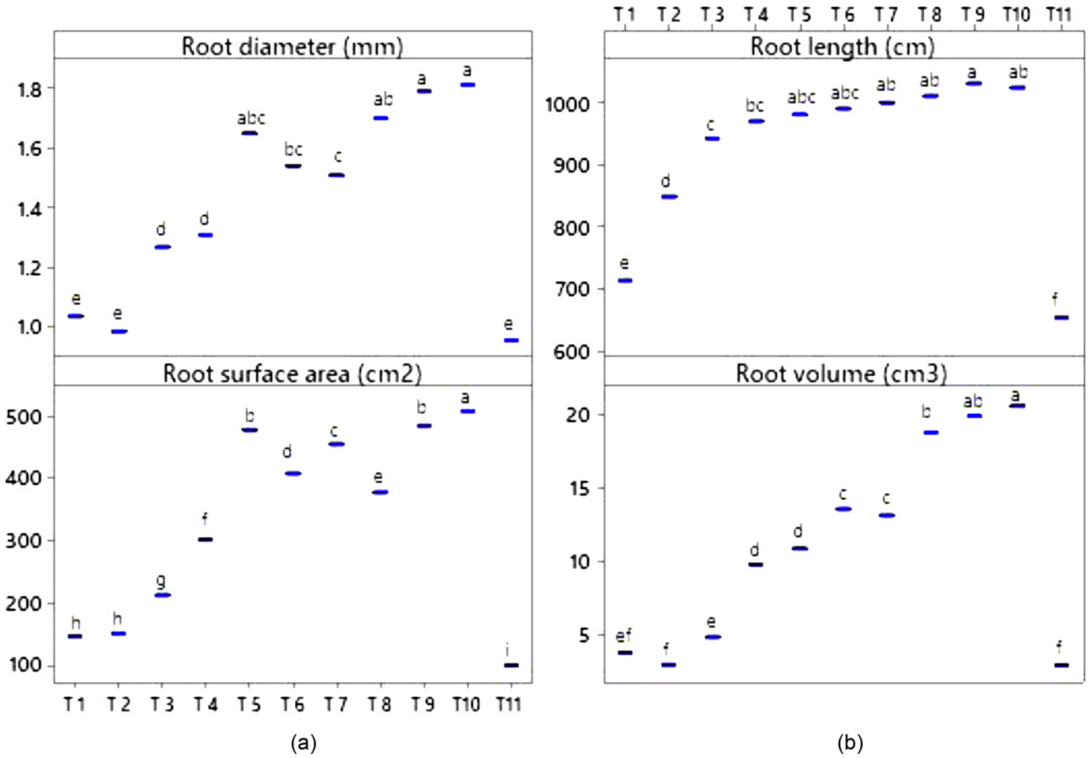


Fig. 3. Influence of diverse nutrient management options on biomass accumulation (dry weight basis) in different parts of Syngonium plants. Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Tukey's HSD test. T1, CRF; T2, water soluble fertilizer (WSF) 1 g; T3, WSF 2 g; T4, WSF 4 g; T5, WSF 1 g + AMF; T6, WSF 2 g + AMF; T7, WSF 4 g + AMF; T8, WSF 1 g + PSB; T9, WSF 2 g + PSB; T10, WSF 4 g + PSB; T11, control.

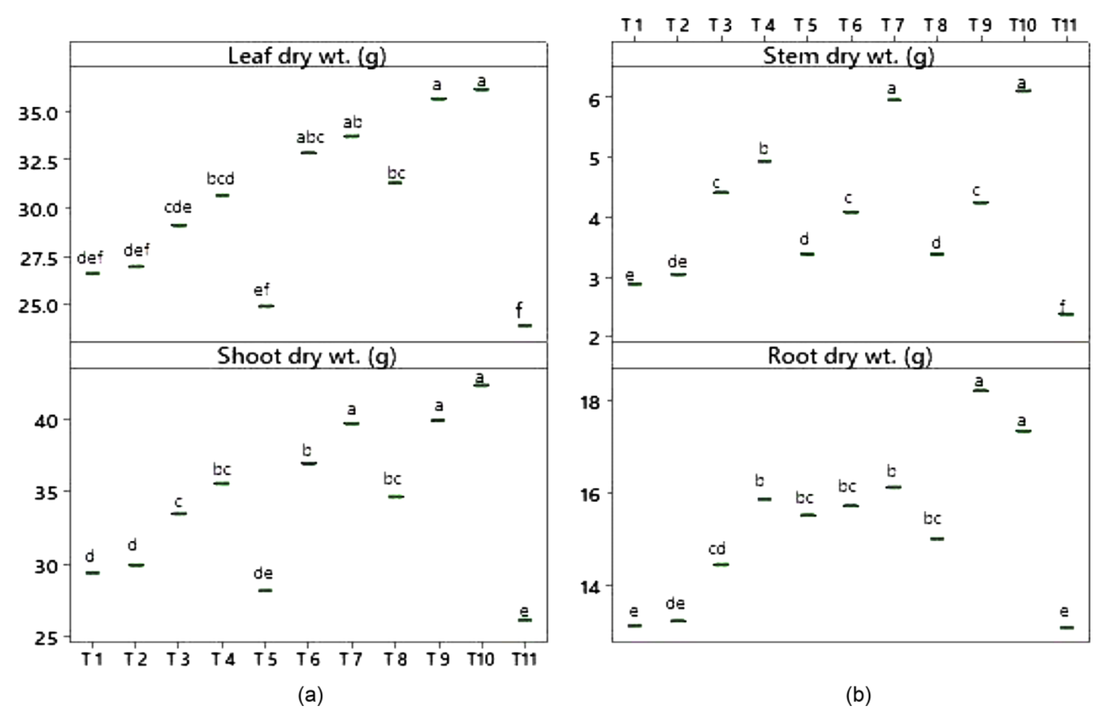
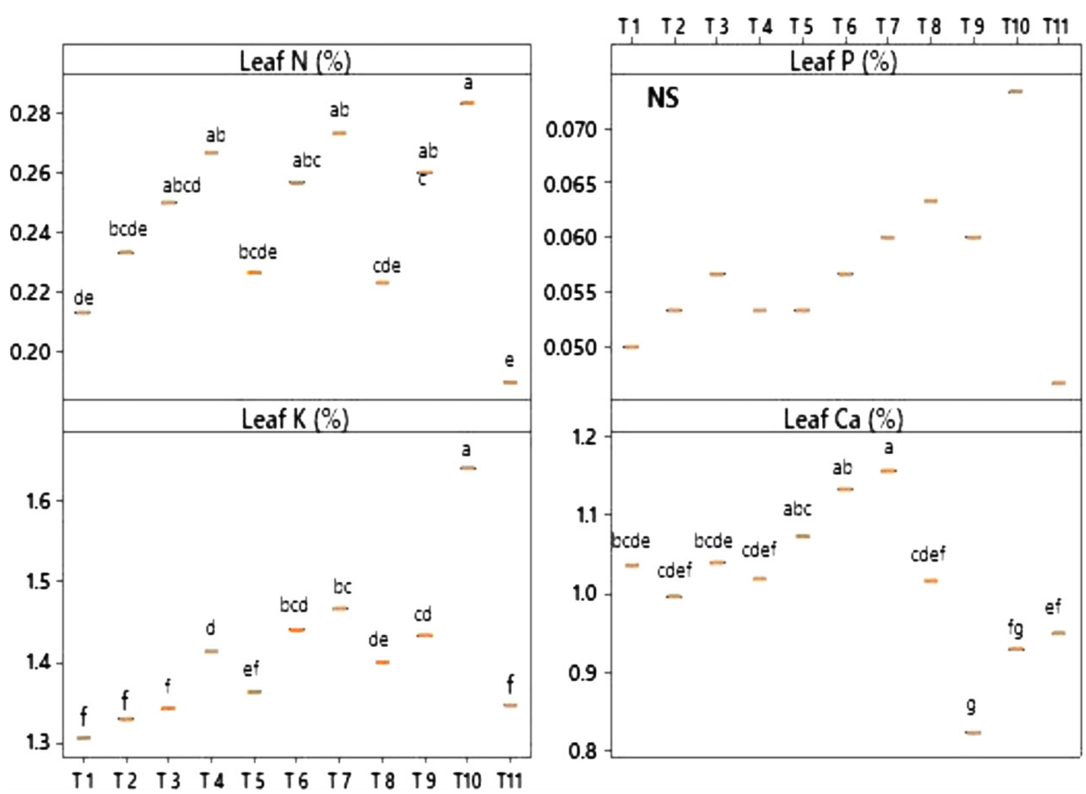


Table 3. Influence of diverse nutrient management options on biomass accumulation (fresh weight basis) in different parts of Syngonium plants.

Treatments	Leaf fresh weight (g)	Stem fresh weight (g)	Shoot fresh weight (g)	Root fresh weight (g)	Root:shoot ratio
T1 CRF	143.87	12.87	156.74	22.40	0.14
T2 WSF 1	153.43	13.20	166.63	19.87	0.12
T3 WSF 2	161.07	14.27	175.34	25.67	0.15
T4 WSF 4	185.93	16.10	202.03	26.00	0.13
T5 WSF 1 + AMF	158.73	13.63	172.36	26.07	0.15
T6 WSF 2 + AMF	241.73	15.97	257.70	26.83	0.10
T7 WSF 4 + AMF	255.13	22.33	277.46	35.97	0.13
T8 WSF 1 + PSB	166.07	14.57	180.64	40.73	0.23
T9 WSF 2 + PSB	226.90	16.10	243.00	48.40	0.20
T10 WSF 4 + PSB	257.50	22.50	280.00	46.73	0.17
T11 Control	140.57	12.20	152.77	17.73	0.12
LSD (P = 0.05)	18.34	2.20	9.60	6.19	0.03

Note: WSF = water soluble fertilizer; AMF = arbuscular mycorrhizal fungi; PSB = phosphorus solubilizing biofertilizer; CRF = commercial fertilizer.

Fig. 4. Influence of diverse nutrient management options on leaf nutrient concentration of Syngonium plants. Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Tukey's HSD test. T1, CRF; T2, water soluble fertilizer (WSF) 1 g; T3, WSF 2 g; T4, WSF 4 g; T5, WSF 1 g + AMF; T6, WSF 2 g + AMF; T7, WSF 4 g + AMF; T8, WSF 1 g + PSB; T9, WSF 2 g + PSB; T10, WSF 4 g + PSB; T11, control.



K content was recorded as highest in T_{10}, while the minimum K content was noted under the control.

Discussion

The increase in plant height, spread, number of leaves, petiole length, and leaf area with the application of WSF and biofertilizers in the present study may be attributed to greater nutrient availability (Fig. 1). The application of essential plant nutrients in the readily available form improves crop growth and productivity. Furthermore, the optimum nutrient schedule increases the nutrient-use efficiency by reducing the loss of nutrients (Bana et al. 2021). The combined effect of WSF and biofertilizers might have supplied an adequate amount of nutrients and favored metabolic activity in the plants, which resulted in better growth and development. Several other researchers while working on various crops have reported the beneficial effect of WSF on plant growth

Table 4. Physico-chemical properties of the media as influenced by the diverse nutrient management options in Syngonium plants.

Treatments	Soil pH	EC (dS m^{-1})	OC (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T1 CRF	7.51	0.35	0.41	205.9	45.8	122.1
T2 WSF 1	6.99	0.41	0.43	203.6	48.0	132.4
T3 WSF 2	7.06	0.46	0.47	209.4	54.4	148.8
T4 WSF 4	7.09	0.48	0.47	218.3	55.6	161.2
T5 WSF 1 + AMF	7.06	0.42	0.45	211.7	52.3	158.3
T6 WSF 2 + AMF	7.16	0.43	0.43	216.4	55.1	174.4
T7 WSF 4 + AMF	7.25	0.43	0.48	221.5	56.4	195.9
T8 WSF 1 + PSB	7.04	0.42	0.44	218.0	52.9	173.4
T9 WSF 2 + PSB	7.10	0.42	0.47	223.5	60.4	191.4
T10 WSF 4 + PSB	7.13	0.41	0.47	226.4	57.4	204.0
T11 Control	6.85	0.30	0.40	202.5	42.8	117.1
LSD ($P = 0.05$)	0.15	0.06	0.02	7.00	3.12	2.11

Note: WSF = water soluble fertilizer; AMF = arbuscular mycorrhizal fungi; PSB = phosphorus solubilizing biofertilizer; CRF = commercial fertilizer.

(Mishra et al. 2011; Bohane and Tiwari 2014; El-Tohamy et al. 2019).

In addition, the microbes present in PSB culture promote plant growth indirectly by increasing the accessibility of other trace elements (Wani et al. 2007; Mahidi et al. 2011; Walpola and Yoon 2012; Santana et al. 2016). PSB protect plants by avoiding phytopathogens, typically owing to the production of antibiotics, hydrogen cyanate, and antifungal metabolites (Hajjam and Cherkaoui 2017). In the present study, better growth under PSB-treated pots might have also been due to the enhanced availability of P due to accelerated cell division and cell enlargement (Assuero et al. 2004).

The activity of the root system was significantly promoted by WSF, which might be used as a plant growth regulator, and improved the physiology of the root system. The combined application of WSF and PSB/AMF increased the root length, root diameter, and root fresh weight by 56%, 88%, and 172%, respectively, over the control treatment. The activity of the root system correlated closely with the concentration of WSF. A high concentration of nutrients in the rhizosphere can influence the osmotic pressure of the root system and consequently its growth and activity (Itoh et al. 1987; Monsuru and Daud 2016). Besides WSF, the use of PSB/AMF as inoculants might have increased phosphorus uptake by plants and finally improved root growth. Similarly, in roses (*Rosa damascena*), root growth, root length, and root fresh and dry weight parameters were positively affected by PGPR (Tariq et al. 2016). The RSR of plants is a quantitative measurement of plant tissues and involves monitoring of the overall health of plants, which is reflected in both the growth and yield of the present findings. The application of fertilizers improved the plant health and enhanced the growth of plant tissues, thus extending the RSR (Monsuru and Daud 2016).

The application of WSF along with microbial cultures significantly enhanced the soil pH and EC (Table 4). The use of WSF with a higher content of mineral nutrients may lead to localized changes in the soil pH in and around the wet zone (Teixeira et al. 2007). An increase in EC was observed due to the addition of higher amount of WSF, which resulted in more cations in the soil solution and thus increased the same. These findings are in line with the work reported by Senthilkumar (2014). Similarly, Ivy et al. (2002) also reported that EC values increased with increasing rates of fertilization in both *Ilex* sp. and *Viburnum* sp. Similarly, Ananda Murthy et al. (2020)recorded the maximum content of organic carbon and EC in soil with WSF. The application of WSF along with PSB resulted in maximum available postharvest macronutrients (N, P & K) in soil. Similar to our findings, Ananda Murthy et al. (2020) observed that soil nutrient status and nutrient uptake also improved with fertigation through WSF 19:19:19. These results corroborate the findings of other workers (Kadam et al. 2009; Abdullahi et al. 2014; Garcia et al. 2017; Khambalkar et al. 2017; Navsare 2017).

The biomass accumulation was significantly higher in plants treated with WSF and PSB (Table 3). Similarly, in alfalfa pot experiment, Chen and Liu (2019) reported that PSB significantly increased plant biomass, root growth, and P uptake due to the production of both acid and alkaline phosphatases, solubilizing various organic and inorganic P such as lecithin. Likewise, Bargaz et al. (2021) reported that the use of PSB as inoculum could simultaneously mobilize the unavailable P from soil and significantly improve P fertilizer-use efficiency, providing unique opportunities for improved P availability in the soil–plant continuum. Many studies confirmed that the combined application of PSB and P fertilizers could further reduce P adsorption in the soil and increase its availability, which consequently will improve P fertilizer-use efficiency. Similarly, N, K, and Ca contents in Syngonium leaves increased by 42%, 26%, and 44%, respectively, over the control treatment (Fig. 3), due to the integrated use of WSF and AMF/PSB. The increase in nutrient content may be attributed to enhanced nutrient availability in the WSF + biofertilizer treatments, mainly owing to direct nutrient application at the site of metabolism and increased nutrient absorption rate and translocation in the plant–soil continuum. Ananda

Murthy et al. (2020) and Bana et al. 2021 also reported increased leaf nutrient content with the foliar application of plant nutrients.

Conclusions

Over the past few decades, the global ornamental plant market has proved to be a promising sector in supporting national economies. Additionally, the market is predicted to have a constant growth rate for the next 5 years. For this reason, experiments have been conducted to improve the nutrient management practices of Syngonium, a high-value ornamental plant. Among various options for nutrient management, WSF have emerged as a potential alternative due to their instant solubility and nutrient availability to the plants, and feasibility in the foliar application and pressurized irrigation.

Additionally, biofertilizers are a cost-effective and environmental-friendly option to be integrated with WSF to augment plant growth and reduce fertilizer requirement. From the present study, it is concluded that WSF (4 g kg^{-1}) in combination with biofertilizers (either PSB or AMF) not only enhanced the Syngonium foliage, biomass production, and root growth but also boosted the postharvest soil fertility and nutrient content in the leaves. Therefore, WSF in combination with PSB and (or) AMF may be recommended as an effective strategy of nutrient management for enhanced productivity of Syngonium plants, mainly owing to better aboveground and belowground growth. For future research work, other diverse nutrient options may be explored with their nutrient release patterns and economic and environmental footprints. Furthermore, foliar nutrition alternatives, including secondary and micronutrients in soil or soil-less media, could be explored as a tool for greater nutrient-use efficiency of different indoor plants in future research.

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