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The use of seaweed in the production of ornamental plants

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Abstract: Ornamental plants play a crucial role in urban green spaces by enhancing aesthetic value and providing ecological and economic benefits. They help improve air quality, support biodiversity, and contribute to environmental purification. The horticultural industry benefits from cultivating ornamental plants, it faces challenges such as soil health and environmental pollution due to high-yielding cultivars and chemical fertilizers. To address these challenges, integrating sustainable practices, such as using seaweed as an organic fertilizer, can provide solutions. Seaweed, rich in essential nutrients and growth hormones, improves soil fertility, plant growth, and resilience against environmental stresses. Studies have shown its effectiveness in enhancing growth parameters, mitigating salinity stress, and increasing yield and quality in various ornamental plants. However, the response to seaweed varies across species and conditions. To optimize its use, tailored application rates, combined sustainable practices, and continuous monitoring are recommended. Further research is also needed to develop comprehensive guidelines for its application in ornamental plant production.
Keywords: Seaweed, Ornamental plant, Organic matter, Plant production, Growth and development

Deniz yosununun süs bitkileri üretiminde kullanımı

Özet: Süs bitkileri, estetik değeri arttırarak, ekolojik ve ekonomik faydalar sağlayarak kentsel yeşil alanlarda çok önemli bir rol oynamaktadır. Hava kalitesinin iyileştirilmesine yardımcı olur, biyolojik çeşitliliği destekler ve çevresel arıtmaya katkıda bulunmaktadır. Süs bitkisi yetiştiriciliği, bahçecilik endüstrisine fayda sağlamaktadır. Ancak, yüksek verimli kültivarlar ve yoğun miktarda kullanılan kimyasal gübreler nedeniyle toprak sağlığı ve çevre kirliliği gibi sorunlarla karşı karşıya kalınmaktadır. Bu sorunların üstesinden gelmek için, deniz yosununun organik gübre olarak kullanılması gibi sürdürülebilir uygulamaların entegre edilmesi çözüm sağlayabilir. Deniz yosunu, temel besin maddeleri ve büyüme hormonları açısından zengin olup, toprak verimliliğini, bitki büyümesini ve çevresel streslere karşı direnci artırır. Çalışmalar, deniz yosununun büyüme parametrelerini geliştirmede, tuzluluk stresini azaltmada, çeşitli süs bitkilerinde verim ve kaliteyi artırmada etkili olduğunu göstermektedir. Ancak, deniz yosununa tepkiler türler ve koşullar arasında değişiklik göstermektedir. Bununla birlikte, deniz yosununa verilen yanıt bitki türlerine ve çevresel koşullara göre değişmektedir. Kullanımını optimize etmek için, özel uygulama oranları, birleşik sürdürülebilir uygulamalar ve sürekli izleme önerilmektedir. Süs bitkisi üretiminde uygulanmasına yönelik kapsamlı kılavuzlar geliştirmek için daha fazla araştırmaya da ihtiyaç vardır.
Anahtar kelimeler: Deniz yosunu, Süs bitkisi, Organik madde, Bitki üretimi, Büyüme ve gelişme

1. Introduction

Ornamental plants have been integral to human environments for centuries, cherished not only for their aesthetic value but also for their numerous benefits. From transforming plain spaces into lush, inviting areas to enhance the visual appeal of parks, gardens, and urban green spaces, these plants play a pivotal role in shaping our surroundings (Thekkayam 2021). Their diverse applications include the creation of elegant lawns, vibrant flower beds, structured borders, and intricate topiaries, all contributing to the overall beauty and functionality of landscapes (Thekkayam 2021, Kovacs et al. 2024).
Beyond their ornamental qualities, these plants provide significant ecological and economic benefits. They are essential in urban green spaces, offering ecosystem services that support both environmental sustainability and human well-being (Kovacs et al. 2024). For instance, ornamental plants enhance air quality by acting as biological filters, supporting biodiversity by providing habitats for wildlife, andcontributing to environmental purification processes (Rocha et al. 2022).
The cultivation and propagation of these plants are central to the horticultural and agricultural industries, highlighting their economic importance. The ornamental sector, encompassing activities such as growing, distributing, and selling flowers and decorative plants, significantly impacts the global economy and agribusiness (Loconsole et al. 2024, Tütüncü et al. 2024). However, the industry faces challenges related to sustainability. The increased use of high-yielding cultivars and chemical fertilizers has led to concerns about soil health and environmental pollution (Sahu et al. 2022). Over-reliance on these practices has compromised the physio-chemical qualities of soil and increased pollution in both soil and water systems. In response, there is a growing emphasis on integrating organic materials and sustainable practices into plant production to address these issues (Çakır et al. 2020, Çiçek et al. 2021, Widnyana et al. 2023).
This study included a thorough review of the literature to investigate the applications of seaweed, one of the

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significant organic components, in the production of various ornamental plants.

2. Ornamental plants

Ornamental plants are cultivated primarily for decorative purposes (Güneş et al. 2019) rather than for food or raw materials, encompassing a broad spectrum of plant species. These plants are intentionally planted for their aesthetic appeal but also serve additional purposes such as providing fragrance, attracting wildlife, and purifying the air (ISAAA 2014). With a few exceptions, such as the flowers of daylilies (Hemerocallis) and nasturtiums (Tropaeolum), ornamental plants are not grown for consumption (Schmidt 2009, ISAAA 2014).

Ornamental plants are categorized into four main groups: cut flowers, outdoor ornamental plants, indoor ornamental plants, and natural flower bulbs (Zencirkiran and Gürbüz 2009). They include a wide variety of species, particularly higher plants, and are classified into various groups including cut flowers, ornamental grasses, lawn or turf grasses, potted and indoor plants, bedding plants, trees, and shrubs (Schmidt 2009, ISAAA 2014). Cut flowers refer to flowers and buds that have been cut from the plant, suitable for use in bouquets, wreaths, corsages, and special flower arrangements (Örük and Örük 2020).

The production of ornamental plants in Turkey for the years 2022 and 2023 is shown in Table 1. The data indicates a substantial increase in the production of indoor plants, while a minor decrease is evident in the production of other ornamental plants.

Table 1. The production of ornamental plant in Türkiye (TÜİK 2024)

	2022		2023		
	Number	%	Number	%	Change
Cut flowers	1 424 921 345	68.5	1 413 978 778	65.3	-0.8
Outdoor ornamental plants	537 962 657	25.9	525 484 719	24.3	-2.3
Flowers bulbs	72 546 322	3.5	67 448 100	3.1	-7.0
Indoor ornamental plants	44 530 347	2.1	156 836 952	7.2	252.2
Total	2 079 960 671	100.0	2 163 748 549	100.0	4.0

3. Seaweed

Climate change, urbanization, and chemical-based soil management practices provide issues for modern agriculture that need for environmentally friendly soil management strategies. In this sense, nutrient-rich seaweed is a powerful soil improver (Korkmaz et al. 2023, Bamaniya et al. 2024). Seaweed, a diverse group of marine algae, has gained prominence for its significant contributions to sustainable agriculture and environmental management. They are classified into three primary groups based on their pigmentation: Rhodophyta (red seaweeds), Phaeophyta (brown seaweeds), and Chlorophyta (green seaweeds) (Bhadarka et al. 2024). Rhodophyta, such as Porphyra (Nori) and Chondrus crispus (Carrageen), are typically found in deeper, warmer waters and are known for their high carrageenan content, which is valuable in various industrial applications. Phaeophyta, including Laminaria (Kelp) and Fucus (Bladderwrack), are prevalent in cooler waters and are rich in alginates, which play a crucial role in soil conditioning. Chlorophyta, such as Ulva (Sea Lettuce) and Codium, thrive in shallow, well-lit waters and are noted for their high chlorophyll content.

The benefits of seaweed in agriculture are extensive due to its rich nutrient profile (Figure 1). Seaweed acts as an effective organic fertilizer and soil conditioner, enhancing soil fertility by adding essential nutrients and organic matter, improving soil structure, and increasing moisture retention, particularly in clay soils. Seaweed-based biostimulants are particularly noteworthy as they stimulate plant growth, improve nutrient uptake, and bolster plant resilience against environmental stresses, making them a sustainable alternative to synthetic fertilizers (Choulot et al. 2022). Seaweed has shown promise in capturing nitrogen runoff and returning it to the soil, further enhancing its role in sustainable agriculture (Seghetta et al. 2016, Bamaniya et al. 2024). They also contribute to improved soil qualities under field conditions, boost crop production and quality, and increase nutrient usage efficiency. Seaweed fertilizers can increase crop yield by an average of 15.17%, with root and tuber crops showing a significant 21.19% increase. Additionally, their application improves crop quality, including increases in starch (19.65%), protein (11.45%), sugar-acid ratio (38.32%), and vitamin C (18.07%) (Pei et al. 2024).

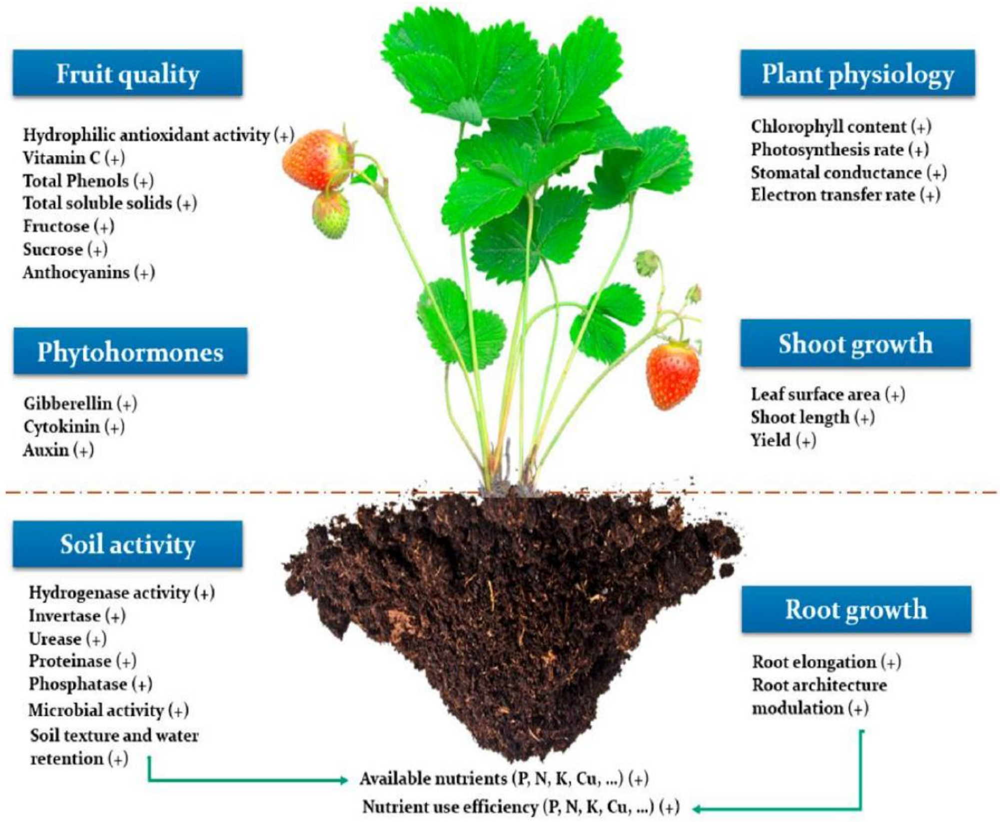

Figure 1. Benefits of seaweed in the production of plants (Pratheeksha and Nagajyothi 2024)

Seaweed extract is also a highly valuable organic substance used in horticulture and agriculture, derived from various types of sea algae. It provides several advantages, such as increased nutrient uptake, enhanced growth of roots and shoots, and improved disease resistance (Chojnacka 2012, Vijayaraghavan and Joshi 2015, Pratheeksha and Nagajyothi 2024). Seaweed meal, which is dried and ground seaweed, is used as a soil conditioner and fertilizer (Bamaniya et al. 2022). In addition to growth hormones, seaweed offers micro- and macronutrients that improve the quality and growth of a wide variety of ornamental plants (Kularathne et al. 2021). Because they enhance plant development and improve crop tolerance to abiotic challenges such salinity, severe temperatures, nutrient deficiencies, and drought, brown seaweed extracts are frequently utilized in horticultural crops (Battacharyya et al. 2015). Brown seaweeds, such as Ecklonia, Fucus, and Ascophyllum, are commonly utilized in large-scale production. They are lower in phosphorus compared to conventional animal manures and standard N:P ratios in chemical fertilizers but provide adequate potassium and nitrogen. The strong moisture retention qualities of insoluble carbohydrates from brown seaweeds enhance soil aeration and structure, especially in clay soils. Additionally, maerl, a fertilizer made from calcareous red algae like *Phymatolithon calcareum* and *Lithothamnion corallioides*, is used to neutralize acid soils as an alternative to agricultural lime (Bamaniya et al. 2022). Due to its many benefits for plant growth, liquid seaweed fertilizer has also recently become quite well-known and well-liked (Yusuf et al. 2022). Seaweeds can be applied to the soil or fertilizer solutions for root application, as well as used in foliar applications on the leaves (Külahtaş and Çokuysal 2016).

Seaweed not only enhances agricultural productivity but also contributes to broader environmental and economic goals, solidifying its role as a valuable resource in modern farming practices.

4. The use of seaweed in the production of ornamental plants

Studies into how seaweed fertilizers affect the production of ornamental plants have recently proliferated. The striking results of these studies are chronologically outlined below.

Spraying *Amaranthus tricolor* irrigated with saline water with seaweed extract effectively mitigated salt stress and improved growth parameters, including stem length and diameter, root length, leaf number, and fresh and dry weights of leaves, stems, and roots. Plants irrigated with 1000 mg L^{-1} saline water and sprayed with 2.5 cm^3 L^{-1} of seaweed extract achieved the highest values for inflorescence stalk length, inflorescence length and number, and both fresh and dry weights of inflorescences. The results suggest that seaweed extract application enhances plant tolerance to salinity, with the optimal effects observed at 2.5 and 3.0 cm^3 L^{-1} seaweed extract and 1000 mg L^{-1} saline water, positively influencing vegetative growth, flowering, and chemical constituents of *A. tricolor* (Aziz et al. 2011).

The ideal plant height, node count, longest root, number of leaves, dry and fresh weights, and plantlet survival in *Robinia pseudoacacia* L. were all achieved with the 1000 mg L^{-1} brown seaweed extracts (Kaviani et al. 2014).

Li and Mattson (2015) found that rockweed (*Ascophyllum nodosum*) extract at a rate of 5–10 mL L^{-1} is suitable for substrate drenches to prolong the postharvest life of *Petunia hybrida* transplants.

During the two tested seasons (2012/2013 and 2013/2014), foliar spraying with 1500 mg L^{-1} of seaweed extract greatly enhanced plant height, the quantity of blooms per plant, and vase life in *Calendula officinalis* L. (Tartil et al. 2016).

Seaweed treatments applied for 1 and 2 days significantly improved germination rates in seeds of *Lavandula angustifolia* compared to the control. Additionally, 2-day seaweed treatment enhanced the germination index. Overall, seaweed treatments positively influence germination parameters in *L. angustifolia* seeds (Demirkaya et al. 2017).

A study (Al-Hamzawi 2019), investigating the effects of seaweed extract (seaweed Fe) and micronutrient mixtures at concentrations of 0-, 1-, and 2-mL L^{-1}on the growth of *Dianthus chinensis* L. and *Gazania splendens* L., demonstrated significant improvements in various growth parameters for both plants. In *D. chinensis*, plant height increased significantly with the use of both materials, particularly at higher concentrations, and leaf number also showed a notable increase with 2 mL L^{-1} of micronutrient mixture. *G. splendens* exhibited a pronounced increase in leaf number with higher concentrations of seaweed extract. While seaweed extract had no effect on the percentage of dry weight, the micronutrient mixture significantly increased this parameter at both concentrations. Both materials enhanced chlorophyll content, flower number, flower stalk length, and flower diameter, although flower fresh and dry weights remained unaffected. Nitrogen percentage in *D. chinensis* leaves increased significantly with both materials, whereas in *G. splendens*, this increase was attributed to seaweed extract, with micronutrients showing no effect. Carbohydrate content in leaves of both plants also increased notably, especially at higher concentrations.

Al-Khuzaey and Al-Asadi (2019) found that *Narcissus tazetta* outperformed the *N. eastertide* in all explored traits, and the optimal concentration was 4 mL^{-1} of seaweed extract.

Increasing the concentration of a seaweed based (*Ascophyllum nodosum*) biostimulant enhances seed germination and seedling development of *Helianthus annuus* cv. “Sol Pleno”. The 15 mL L^{-1}concentration of the biostimulant achieved the best results, including higher germination percentage and index, shorter mean germination time, and greater plant height, as well as increased fresh and dry mass of shoots compared to the control treatment. Therefore, a 15 mL L^{-1}concentration of this biostimulant is recommended for optimizing seed germination and seedling growth in cultivar “Sol Pleno” (Santos et al. 2019).

When compared to the control plants, the application of Stimplex®, a commercial liquid seaweed extract, to *Capsicum annuum* L. increased the following traits: stem diameter, plant height, number and area of leaves, leaf chlorophyll content, shot fresh weight, shoot dry weight, root fresh weight, and dry weight (Ozbay and Demirkıran 2019).

Sumangala et al. (2019) found that applying a liquid seaweed fertilizer at a 20% concentration once a week has the potential to increase the number of flowers in *Rosa sp*. plants.

Ayyat and Abdel-Mola (2020) assessed the impact of seaweed extract on the vegetative and flowering growth parameters and essential oil percentage of *Tagetes patula*. Foliar applications of seaweed extract (3 mL $L^{-1}$and 5 mL L^{-1}) significantly improved all parameters compared to the control. The most pronounced effects were observed with the combination of potassium silicate (5 mL L^{-1}) and seaweed extract (5 mL L^{-1}), especially when plants were irrigated every one or two days. This combination yielded the highest growth parameters and essential oil percentage in both seasons. Thus, to mitigate drought stress, it is recommended to treat *T. patula* with high concentrations of potassium silicate and/or seaweed extract (5 mL L^{-1}).

A study (El-Naggar et al. 2020) recommends economically and environmentally sustainable fertilization of *Ocimum basilicum* L. using a combination of dry yeast and seaweed extract. Specifically, applying dry yeast at 4 or 6 g L^{-1} and seaweed extract at 4 g L^{-1} as foliar sprays will optimize growth, enhance oil yield, and ensure a safe chemical composition for *O. basilicum*.

Mousa et al. (2020) found that seaweed extract outperformed alternative treatments (salicylic acid, dry yeast and moringa leaf extract) in improving plant tolerance to salinity, as seen by the significant increase in the growth and volatile oil content of *Ocimum basilicum* L.

All explored traits pertaining to seed germination and the growth and development of seedlings in *Tagetes erecta* was improved by the seaweed extract. 15 mL L^{-1} seaweed extract resulted in the best results. The study suggests applying seaweed extract as a natural biostimulant on *T. erecta* crops to enhance seed germination and seedling growth (Tavares et al. 2020).

Spraying 6 g L^{-1} of licorice extract and 8 ml/L of seaweed extract on *Nerium oleander* L. leaves markedly raised the amounts of protein, alkaloids, phenols, tannins, and saponins. This treatment improved the overall production of plant chemicals, boosted photosynthesis, and increased plant growth (Al-Bahadly and Radhi 2021).

Research (Alhasan et al. 2021), assessing the impact of varying rates of seaweed extract (0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 g L^{-1}) on the growth and flower production of *Gerbera jamesonii* L., revealed statistically significant differences in plant growth parameters and flower yield due to the application of seaweed extract as an organic fertilizer. Notably, the highest application rate of 3.0 g L^{-1} positively influenced both growth and flower production, demonstrating its effectiveness under shade net conditions.

The application of biostimulants based on seaweed can guarantee the generation of high-quality seedlings of *Viola tricolor* var. *hortensis* DC. by preventing temperature stress and promoting good nutrient uptake through the decrease of fertilizer and environmental contamination (Zeljkovic et al. 2021).
The survival rate and root biometric parameters of both “Michelangelo” and “Cosmos” cuttings were enhanced by Kelpak® seaweed extract, demonstrating its usefulness as a substitute for synthetic chemicals used in rooting promotion during rose propagation (Traversari et al. 2022).
In a study (Yılmaz et al. 2022), application of 1 g L^{-1} seaweed produced statistically significant results in terms of total phenolic content and antioxidant capability without stressing *Salvia fruticosa*.
Yusuf et al. (2022) found that the number of leaves, plant height, and branches in *Chrysanthemum sp.* all changed significantly throughout the vegetative phase when 80 mililiters (1 liter) of liquid seaweed fertilizer was applied. The number of flowers, flower diameter, and flower blooming duration are all unaffected by the flowering.
Increasing doses of liquid seaweed fertilizer did not have a positive effect on the quality, growth, or physiological traits of *Viola tricolor* L (Çiçek 2023).
De Clercq et al. (2023) explored the effects of four seaweed extracts - *Ascophyllum nodosum, Soliera chordalis, Ecklonia maxima,* and *Saccharina latissimi* - as well as one microbial biostimulant on container-grown *Hydrangea paniculata* under drought stress over two years. Reduced irrigation led to lower substrate moisture content, decreased stomatal conductance, biomass production, and root development, but increased plant compactness. The biostimulants had minimal effects, which were not consistently observed across both experiments. Notably, *A. nodosum* extract improved branch length and biomass under deficit irrigation and accelerated flowering under drying and wetting cycles. In contrast, *E. maxima* extract had a negative impact on branching during repeated drying and wetting cycles.
A study (Jena and Topno 2023), examining the impact of applying seaweed extract on the growth, flowering, and yield of *Viola x wittrockiana* in the winter of 2022-2023, revealed that treatment T4, which involves the application of seaweed extract at 4 mL L^{-1}as a drench, was superior in several growth and flowering parameters (plant height, plant spread, branches per plant, the earliest flowering with the first flower opening, flowering time, stalk length, flower diameter, leaves per plant, flowers per plant, and seed yield per plant).
Amino-acid outperformed seaweed extract in improving the qualitative performance of *Abelia x grandiflora* and *Lantana camara* transplants under a 50% controlled release fertilizers mineral nutrient supply limitation (Loconsole et al. 2023a).
When compared to the untreated control, neither seaweed extract - Kelpak® or Goteo® - at different concentrations enhanced the ground or above-ground weights of rooted cutting in *Photinia x fraseri* Dress cv. “Red Robin”. This suggests that these natural products are inappropriate for this cultivar’ propagation (Loconsole et al. 2023b).
The plant height, number of branches per plant, branch diameter, shoot dry weight, number of flowers per plant, flower diameter, and root length in *Linum grandiflorum* L. were all increased by the seaweed extract spraying (Sorour and Hassan 2023).
According to a study (Zouari et al. 2023), the application of liquid seaweed (*Ulva rigida*) greatly boosted the growth and roots of *Ceratonia siliqua* L. cuttings. In comparison to the untreated *C. siliqua* plants, the liquid seaweed-treated plants performed better in terms of plant height, the numbers of internode, leaf and root, and root length, with a high rooting percentage of 83%. The adventitious roots of *C. siliqua* hypocotyl cuttings exhibited a greater response when treated with a combination of Indole butyric acid (IBA) at a dosage of 2 mg L^{-1} and culturing in a medium containing 4% liquid seaweed. Furthermore, liquid seaweed fertilizer had a major impact on *C. siliqua* root growth.
Applying seaweed liquid helped to mitigate the deleterious impact of the rising NaCl concentrations on all explored characteristics of *Lavandula officinalis*. In the absence of salt stress, seaweed liquid likewise showed the highest values for all explored characteristics. When the salt level increased from 0 to 40 mM, photosynthetic and biochemical traits without proline, relative water content, and chlorophyll a/b decreased more than other quality and growth parameters (Korkmaz and Çiçek 2024).
According to a study (Kovacs et al. 2024), Kelpak® seaweed extract had negative impacts on morphological and physiological traits of *Weigela florida* cv. “Eva Rathke”.

5. Conclusion and suggestions

Ornamental plants are crucial to enhancing urban green spaces, providing aesthetic, ecological, and economic benefits. Seaweed, as an organic fertilizer and biostimulant, has shown promise in improving the growth and resilience of these plants. In contrast to crops of fruits and vegetables, ornamental plants are explored much less frequently in scientific research. Studies on ornamental plants reveal that seaweed extracts can enhance various growth parameters, mitigate environmental stresses, and improve plant health and productivity. These positive effects are attributed to the rich nutrient profile of seaweed, including essential macro- and micronutrients, growth hormones, and other bioactive compounds.
However, the efficacy of seaweed extracts can vary based on plant species, application rates, and environmental conditions. For instance, while seaweed extracts have significantly improved growth in plants like *Amaranthus tricolor* and *Calendula officinalis*, they have shown negative impacts on *Weigela florida* cv. "Eva Rathke". This suggests that the response to seaweed treatments is not universally positive and requires careful consideration of specific plant needs and conditions.
To optimize the use of seaweed in ornamental plant production, it is recommended to:

Tailor Application Rates: Adjust the concentration of seaweed extracts based on plant species and desired outcomes, avoiding over-application.

Combine with Other Sustainable Practices: Integrate seaweed treatments with other organic and sustainable practices to enhance soil health and plant resilience.

Monitor Plant Responses: Regularly assess the physiological and morphological responses of plants to seaweed applications to ensure optimal growth and health.

Conduct Further Research: Investigate the long-term effects of seaweed extracts on a wider range of ornamental plants to develop more comprehensive guidelines for their use.

These strategies will help harness the full potential of seaweed in promoting sustainable ornamental plant production and urban green space management.

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