



Effects of Different Foliar-applied Organic Fertilisers on Early Morpho-physiological Development in Forage Soybean [*Glycine max* (L.) Merr.] Varieties

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ABSTRACT

Background: Due to the burgeoning interest in sustainable and eco-friendly agricultural practices, organic-based fertilizers have become increasingly pivotal in enhancing plant growth and physiological performance. Accordingly, this study evaluated the effects of vermicompost, seaweed and humic acid applications on the morpho-physiological development of Yemsoy and Yeşilsoy soybean varieties [*Glycine max* (L.) Merr.] cultivated for fodder production.

Methods: The experiment was conducted in a randomized complete block design with four replications. Vermicompost, seaweed and humic acid were applied and plant height, leaf area, stem diameter, number of leaves, leaflet width and length and SPAD values were measured during three measurement periods. The applications were initiated at the V2 growth stage of soybean (two-leaf stage) and repeated at 15-day intervals, resulting in a total of three applications. The data were evaluated using analysis of variance (ANOVA).

Result: ANOVA results showed that fertilizer treatments and measurement periods had statistically significant effects on all parameters at the 1% level ($P < 0.01$). In the first measurement period, vermicompost produced the highest plant height, while seaweed increased leaf area by 82% compared to the control group. In the second period, vermicompost increased plant height by 52.2% in Yemsoy and 47.1% in Yeşilsoy compared to the control. During the third period, plant height reached approximately 50 cm and leaf number increased to 8.5-9 per plant under vermicompost application, representing the highest values among the treatments. Overall, vermicompost was the most effective treatment, providing a 38-80% improvement in vegetative growth parameters compared to the control. Seaweed enhanced stem and leaf structure, whereas humic acid resulted in a 12-30% increase compared to the control but remained less effective than the other treatments.

Key words: Forage soybean, Humic acid, Seaweed extract, Vermicompost.

INTRODUCTION

The rapid growth of the global population places increasing pressure on agricultural lands, making it essential to improve production efficiency and maintain yield stability to ensure food security. Mineral fertilizers have long been used to sustain nutrient balance and increase crop productivity; however, their excessive use may pose risks to ecosystem health and human well-being (Wang *et al.*, 2020; Liu *et al.*, 2021). Therefore, the use of organic and biofertilizers has gained increasing importance in sustainable agricultural systems (Glala *et al.*, 2013; Vishwanatha *et al.*, 2022). Environmentally friendly alternatives such as seaweed extracts, humic acid and vermicompost have attracted considerable attention due to their positive effects on soil fertility and plant growth (Colla and Rouphael, 2015; Choudhary *et al.*, 2025). In addition, foliar fertilization has emerged as an effective strategy for improving plant nutrition by enabling rapid nutrient uptake through leaves and correcting deficiencies during critical growth stages (Singh *et al.*, 2013; Rajasekar *et al.*, 2017).

Sustainability in crop production is also closely linked to livestock production systems. The increasing demand for animal-based foods has led to a steady rise in global

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meat consumption, which is expected to reach 51.5 kg per capita by 2050 (Safdar *et al.*, 2023). This trend increases the demand for forage crops and intensifies competition for land between human food and animal feed production (FAO, 2017). Among forage legumes, soybean [*Glycine max* (L.) Merr.] stands out as a strategic crop due to its high protein content, palatability and adaptability, making it an important protein source for both human nutrition and animal feeding (Zhang *et al.*, 2015; Qin *et al.*, 2022; Blount *et al.*, 2017).

This study was conducted to determine the effects of different organic foliar fertilizers on plant growth, morphological traits and chlorophyll content during the early growth stages of fodder soybean [*Glycine max* (L.) Merr.], which holds a strategic position among forage crops.

MATERIALS AND METHODS

The experiment was conducted in 2025 in a climate-controlled growth chamber at the Department of Field Crops, Faculty of Agriculture, Van Yüzüncü Yıl University, using a completely randomized design (CRD) with four replications. The physicochemical properties of the experimental soil are presented in Table 1.

Two forage soybean [*Glycine max* (L.) Merr.] varieties, 'Yemsoy' and 'Yeşilsoy', were used as plant materials. The experiment was conducted under a 16 h light/8 h dark photoperiod. Diammonium phosphate (DAP; 18% N-46% P) was applied to all pots as a basal fertilizer before sowing. The treatments consisted of four groups: (1) control (DAP only), (2) DAP + seaweed extract (OCEAN), (3) DAP + vermicompost (RIVASOL) and (4) DAP + humic acid (GLADIATOR). Foliar fertilizers were applied starting at the V2 (two-leaf) growth stage and repeated three times at 15-day intervals according to the manufacturers' recommendations. Sowing was performed on 15 January 2025 and irrigation was uniformly applied based on soil moisture conditions.

Morpho-physiological measurements were conducted 15 days after the final foliar application. In each pot, the single plant was measured for height from the point where the cotyledons abscised after emergence to the apical meristem using a ruler and the total number of leaves per plant was counted manually. Stem diameter, leaflet width and leaflet length were measured using a digital caliper. Relative chlorophyll content (SPAD values) was recorded using a SPAD-502 chlorophyll meter. Leaf area was calculated using the easy leaf area software and the leaf area index (LAI) was determined following the methods described by Watson (1947) and Easlon and Bloom (2014).

RESULTS AND DISCUSSION

According to the results of the analysis of variance (ANOVA), the effects of fertilizer treatments and measurement time on all examined morpho-physiological parameters were statistically significant at the 1% probability level ($P < 0.01$). For plant height, the main effects of variety, fertilizer and measurement time, as well as the variety $\times$ fertilizer and fertilizer $\times$ measurement time interactions, were significant at the 1% level. In contrast, for leaf area, leaflet width and leaflet length, all main factors, all two-way interactions and the three-way interaction of variety $\times$ fertilizer $\times$ measurement Time were found to be significant at the 1% level. The effect

of variety on stem diameter and number of leaves was not significant; however, the interaction between fertilizer and measurement time significantly influenced these traits at the 1% level. For SPAD values, the Fertilizer $\times$ Measurement Time interaction was significant at the 1% level, whereas the three-way interaction (Variety $\times$ Fertilizer $\times$ Measurement Time) was significant at the 5% level (Table 2).

Initial measurement period

During the initial measurement period (15 days after the V2 growth stage), the highest plant height values in both soybean varieties were obtained from the vermicompost treatment. Plant height reached 21.9 ± 0.3 cm in Yemsoy and 23.3 ± 0.3 cm in Yeşilsoy, representing increases of approximately 34.4% and 36.3% compared with the control, respectively. For leaf area, the highest values in both varieties were recorded under the seaweed treatment, showing an increase of about 81.8% compared with the control. Vermicompost and humic acid applications also increased leaf area but were statistically grouped together. Stem diameter was not significantly affected by fertilizer treatments during the early growth stage and no differences were observed between varieties. In terms of leaf number, vermicompost, seaweed and humic acid treatments were classified within the same statistical group in both varieties, showing slight increases compared with the control. Leaflet width and length were highest under the seaweed treatment in both varieties. In Yeşilsoy, leaflet width reached 24.5 ± 0.3 mm, while in Yemsoy it reached 23.9 ± 0.3 mm, representing increases of approximately 33.9% and 29.9% over the control, respectively. Similarly, leaflet length increased to 29.5 ± 0.3 mm in Yemsoy and 35.2 ± 9.88 mm in Yeşilsoy under the seaweed application. SPAD values were also highest under seaweed treatment. In Yemsoy, SPAD reached 36.4 ± 0.27 (38.9% higher than the control), while in Yeşilsoy the highest values were obtained from seaweed (35.9 ± 0.3) and vermicompost (35.5 ± 0.3), corresponding to increases of 31.0% and 29.6%, respectively (Fig 1).

Second measurement period

During the second measurement period, pronounced differences among treatments were observed in both soybean cultivars, with vermicompost emerging as the most effective application in promoting plant growth. The highest plant height values were recorded under vermicompost application, reaching 37.6 ± 0.3 cm in the Yemsoy cultivar and 38.7 ± 0.3 cm in the Yeşilsoy cultivar. In contrast, the lowest plant heights were obtained from the control treatment, with values of 24.7 ± 0.3 cm and 26.3 ± 0.3 cm, respectively, corresponding to increases of 52.2% in Yemsoy and 47.1% in Yeşilsoy compared with the control.

Table 1: Physical and chemical properties of the soil used in the experiment.

Depth (cm)	Texture class	pH	Lime (%)	Phosphorus (%)	Organic matter (%)	Total salt (%)
0-20	Clay-loam	7.72	17.90	6.71	1.85	0.042

Table 2: Analysis of variance (ANOVA) for morpho-physiological traits of forage soybean [*Glycine max* (L.) Merr.] as affected by variety, fertilizer treatments and measurement time.

	Plant height		Leaf area		Stem diameter		Leaf number		Leaflet width		Leaflet length		SPAD	
	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Variety	48.02	533.56**	0.01	1341.81**	0.12	1.39	0.01	0.01**	8.4	93.39**	13.52	150.22**	0.28	3.13
Fertilizer	380.91	4232.33**	0.12	35689.63**	1.51	16.78**	3.68	45.10**	215.91	2398.96**	287.69	3196.56**	470.31	5225.72**
Measurement time	3208.7	35652.26**	1.68	496558.33**	6.15	68.35**	113.76	1392.95**	3192.29	35469.88**	4848.87	53876.38**	365.09	4056.51**
Variety × fertilizer	5.86	65.15**	0.01	148.59**	0.05	0.54	0.16	1.97	1.67	18.57**	0.2	2.26	13.37	148.53**
Variety × measurement time	0.08	0.85	0.01	341.08**	0.05	0.51	0.12	1.48	6.2	68.93**	0.92	10.26**	0.07	0.79
Fertilizer × measurement time	21.25	236.10**	0.02	5893.53**	0.31	3.40**	0.5	6.08**	20.44	227.12**	22.43	249.26**	5.17	57.44**
Variety × fertilizer × measurement time	1.03	11.5	0.01	65.94**	0.01	0.16	0.08	0.99	1.32	14.62**	2.51	27.86**	0.27	2.98*

*: p<0.05, **: p<0.01.

In terms of leaf area, vermicompost application in the Yemsoy cultivar (0.48 ± 0.28) resulted in a 54.8% increase relative to the control, whereas the highest leaf area in the Yeşilsoy cultivar was obtained from the seaweed treatment (0.45 ± 0.26), representing an increase of 66.6% over the control. Regarding stem diameter, the seaweed application produced the highest values in both cultivars (3.1 ± 0.3 mm in Yemsoy and 3.4 ± 0.3 mm in Yeşilsoy), corresponding to increases of 55% and 70%, respectively, compared with the control. For leaf number, vermicompost application resulted in the highest value in both cultivars (5.3 ± 0.3 leaves per plant), providing a 15.2% increase relative to the control. Leaflet width was highest under vermicompost application in the Yemsoy cultivar (38.0 ± 0.3 mm, 30.6% increase), while the seaweed application was most effective in the Yeşilsoy cultivar (33.9 ± 0.3 mm, 29.8% increase). Similarly, leaflet length reached its maximum under the seaweed application in both cultivars, measuring 48.1 ± 0.3 mm in Yemsoy and 29.6 ± 0.3 mm in Yeşilsoy, which corresponded to increases of 25.9% and 39.6%, respectively, compared with the control. With respect to SPAD values, vermicompost application in the Yemsoy cultivar produced the highest chlorophyll content (45.8 ± 0.3), representing a 48.7% increase over the control, whereas the seaweed application in the Yeşilsoy cultivar yielded the highest SPAD value (41.1 ± 0.3), corresponding to a 35.0% increase (Fig 2).

Third measurement period

During the third measurement period, increases in all growth parameters continued and the effects of the treatments became more pronounced. In terms of plant height, the highest values in both soybean cultivars were obtained from the vermicompost treatment, reaching 50.3 ± 0.3 cm in Yemsoy and 50.0 ± 0.3 cm in Yeşilsoy, whereas the lowest values were recorded in the control treatment (34.7 ± 0.3 cm and 37.3 ± 0.3 cm, respectively).

For leaf area, the seaweed treatment resulted in the highest values in both cultivars (0.81 ± 0.01 in Yemsoy and 0.78 ± 0.03 in Yeşilsoy), showing marked increases compared to the control. Stem diameter was most strongly enhanced by vermicompost application, with values of 3.6 ± 0.3 mm in Yemsoy and 3.5 ± 0.3 mm in Yeşilsoy, indicating a clear improvement over the control treatment. Regarding leaf number, vermicompost was distinctly superior in both cultivars, producing 9.03 ± 0.25 leaves per plant in Yemsoy and 8.53 ± 0.21 leaves per plant in Yeşilsoy, which represented the highest increases relative to the control. Leaflet width also reached its maximum under vermicompost application (48.3 ± 0.3 mm in Yemsoy and 47.4 ± 0.3 mm in Yeşilsoy), resulting in significant differences compared to the control in both cultivars. In contrast, leaflet length was most effectively promoted by the seaweed treatment, with values of 58.4 ± 0.3 mm in Yemsoy and 46.1 ± 0.3 mm in Yeşilsoy, substantially exceeding those of the control. In terms of SPAD values, vermicompost application produced the highest chlorophyll content in both

cultivars (46.3 ± 0.3 in Yemsoy and 44.8 ± 0.3 in Yeşilsoy), yielding significantly higher results than the control (Fig 3).

Overall evaluation based on the mean values of three measurement periods

The overall evaluation based on the arithmetic means of three measurement periods clearly revealed differential responses of the Yemsoy and Yeşilsoy soybean cultivars

to the applied organic fertilizers. The general results indicated that vermicompost application produced the highest effects on almost all morpho-physiological parameters when compared with the control treatment. In particular, plant height showed marked increases under vermicompost application, reaching 38.77% in Yeşilsoy and 44.27% in Yemsoy relative to the control. Similarly, substantial improvements were observed in leaf area, with

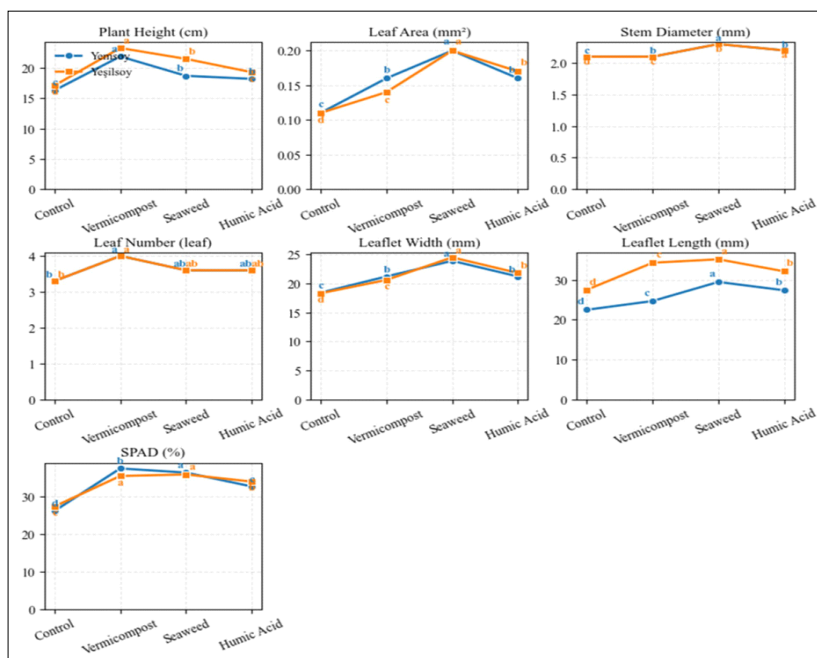


Fig 1: Effects of foliar applications of organic fertilizers on morphological and physiological traits of soybean cultivars during the first measurement period.

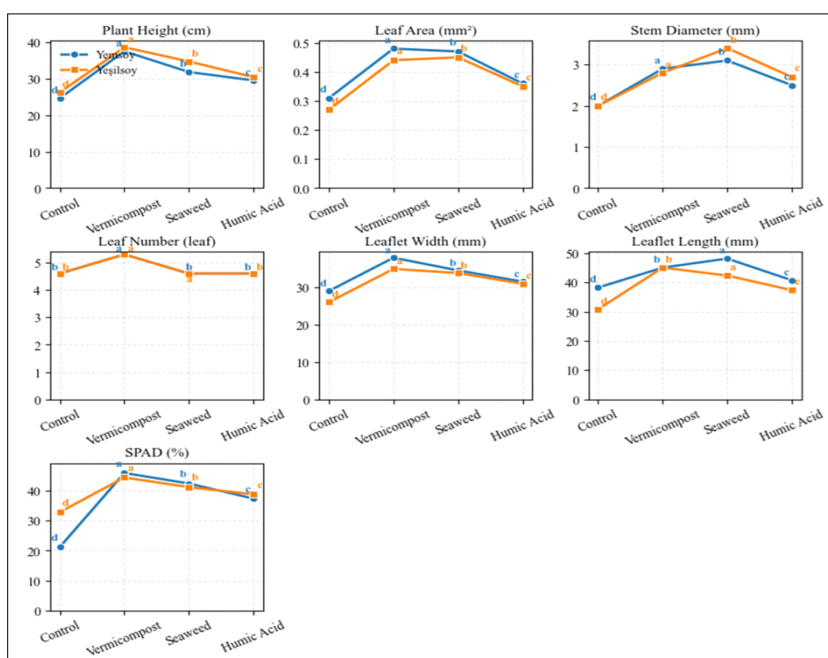


Fig 2: Effects of foliar applications of organic fertilizers on morphological and physiological traits of soybean cultivars during the second measurement period.

increases of 80.00% in Yeşilsoy and 77.42% in Yemsoy, further confirming the superior performance of vermicompost. Leaf number followed a comparable trend, reinforcing the overall effectiveness of this treatment. From a physiological perspective, a similar pattern was observed, as vermicompost application most strongly stimulated chlorophyll synthesis, increasing SPAD values in the Yemsoy cultivar by 44.97% compared to the control. However, seaweed application was more prominent for certain traits. Notably, stem diameter increased by 30.43% in the Yeşilsoy cultivar and leaflet length increased by up to 54.33% in the Yemsoy cultivar relative to the control, indicating that seaweed can be more effective for specific parameters. Although humic acid application contributed positively to all evaluated traits compared to the control, the magnitude of these increases generally remained within the range of 12-30%, placing it behind vermicompost and seaweed treatments in overall effectiveness. When cultivar-specific responses were considered, Yeşilsoy showed higher baseline performance under control conditions, but the highest values and percentage increases were mostly observed in Yemsoy, indicating a stronger response to vermicompost and seaweed applications (Fig 4).

Global challenges such as climate change, soil degradation and rapid population growth have intensified the need for sustainable and efficient plant nutrition strategies that minimize the environmental risks associated with conventional fertilization practices (Schjørring and Cakmak, 2014; Prasad and Shivay, 2020). The findings of the present study demonstrate that organic-based foliar

fertilizers induce multidimensional, time-dependent and genotype-specific improvements in plant morphology and physiology (Sohail *et al.*, 2025; Xu *et al.*, 2025). The analysis of variance confirmed that the applied foliar fertilizers exhibited cumulative effects across growth stages, with their influence becoming more pronounced over time. A notable observation was the absence of statistically significant differences among treatments for stem diameter during the first measurement period. This response can be attributed to the physiological priorities of soybean during the early seedling stage. Large-seeded legumes such as soybean primarily rely on the rapid metabolic activation and breakdown of cotyledonary reserves to meet initial energy requirements rather than external nutrient stimuli (Meneguzzo *et al.*, 2021; Xu *et al.*, 2025). During this establishment phase, early growth is mainly directed toward vertical elongation driven by apical dominance to maximize light interception (Meneguzzo *et al.*, 2021). Furthermore, the limited leaf surface area at this stage likely restricts nutrient absorption from foliar applications, resulting in more pronounced treatment effects only during later measurement periods when leaf area and photosynthetic activity have increased (Li *et al.*, 2018; Bârdas *et al.*, 2023).

As vegetative growth progressed, vermicompost application consistently exhibited superior performance across nearly all evaluated parameters. During the second measurement period, vermicompost increased plant height by 52.2% in Yemsoy and 47.1% in Yeşilsoy, while in the third period it produced the highest values for leaf number (9.03 ± 0.25 leaves plant⁻¹ in Yemsoy) and leaf area

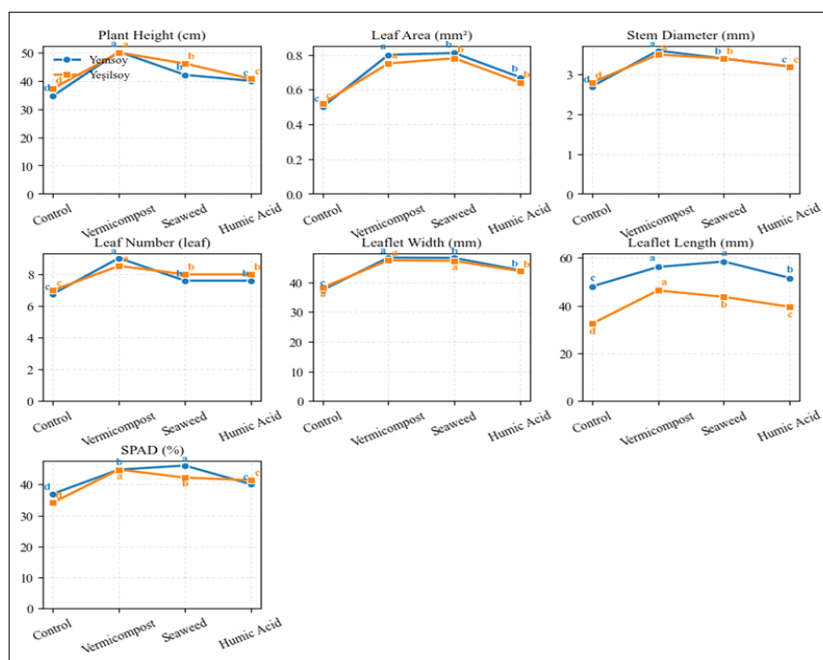


Fig 3: Effects of foliar applications of organic fertilizers on morphological and physiological traits of soybean cultivars during the third measurement period.

(80.00% increase in Yeşilsoy), underscoring its key role in promoting overall biometric development. This comprehensive enhancement can be attributed to the high microbial activity of vermicompost and its content of growth-regulating substances that stimulate cell division and expansion (Ataklı Bice *et al.*, 2022; Kumar *et al.*, 2024). From a physiological perspective, vermicompost markedly promoted chlorophyll biosynthesis, as evidenced by a 44.97% increase in SPAD values in the Yemsoy cultivar compared with the control. This response suggests that micronutrients such as zinc (Zn) and copper (Cu) present in vermicompost effectively activate photosynthetic processes and electron transport mechanisms (Ataklı Bice *et al.*, 2022; Beyk-Khormizi *et al.*, 2023; Iqbal *et al.*, 2024). In contrast, seaweed application exerted a distinct influence on plant architecture, particularly during early growth stages, where it increased leaf area by 81.8% in both cultivars. In later stages, seaweed application resulted in a remarkable 70% increase in stem diameter in Yeşilsoy, indicating a substantial contribution to structural robustness. These effects are consistent with previous

reports attributing such responses to alginates, betaines and cytokinin-like phytohormones in seaweed extracts, which stimulate leaf blade expansion and strengthen vascular tissues (Ali *et al.*, 2021; Shukla *et al.*, 2019).

Although humic acid positively influenced all traits compared with the control, improvements generally ranged from 12-30%, making it less effective than vermicompost and seaweed. Yemsoy showed a stronger response to organic inputs than Yeşilsoy, highlighting the role of genotype in fertilization efficiency. Overall, seaweed can enhance biometric stability and plant architecture, while vermicompost effectively increases vegetative biomass and chlorophyll content. These findings support environmentally friendly agricultural objectives (Zulfiqar *et al.*, 2020) and underscore the importance of organic foliar fertilizers during the early vegetative stage for long-term soybean productivity.

Early-stage biometric advantages are not transient; rather, they establish the foundation for yield potential throughout the plant life cycle. Enhanced vegetative growth primarily maximizes the plant's photosynthetic capacity. Increased leaf area and chlorophyll content achieved



Fig 4: Overall effects of organic foliar fertilizer applications on morpho-physiological traits based on the mean values of three measurement periods.

through vermicompost application enable maximum light interception and energy production prior to critical reproductive stages such as flowering and seed filling. Previous studies have emphasized that a rapidly increasing leaf area index (LAI) during early growth in soybean is strongly and positively correlated with final grain yield, particularly before flowering (Board and Modali, 2005; Ferreira *et al.*, 2024). Simultaneously, the thicker stems and increased plant height associated with seaweed application strengthen the plant's ability to support greater biomass and, more importantly, enhance the vascular system responsible for efficient translocation of photosynthates from leaves to developing pods and seeds (Ambika and Sujatha, 2016; Kocira *et al.*, 2018; Shukla *et al.*, 2021). Therefore, the positive effects of organic foliar fertilizers observed during early growth stages represent a crucial first step toward achieving a successful soybean harvest.

CONCLUSION

This study demonstrated that vermicompost showed the highest performance in key growth traits, including plant height, leaf number and chlorophyll content, while seaweed was particularly effective in improving structural attributes such as leaf area and stem diameter. The stronger response of the Yemsoy cultivar highlights the importance of integrating cultivar selection with fertilization strategy in sustainable agriculture. These organic foliar applications optimized both physiological capacity and morphological resilience, with vermicompost recommended to enhance vegetative biomass and photosynthetic capacity and seaweed to improve structural stability and leaf expansion. Positive effects observed during the early vegetative stage are expected to contribute to harvest index and final yield, emphasizing the strategic role of early-stage organic foliar fertilization in sustainable soybean cultivation.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

- Ali, O., Ramsubhag, A. and Jayaraman, J. (2021). Biostimulant properties of seaweed extracts in plants: Implications towards sustainable crop production. *Plants*. **10**(3): 531.
- Ambika, S. and Sujatha, K. (2016). Organic seaweed nano powder effect on growth and yield attributes of pigeonpea. *Legume Research-An International Journal*. **40**(4): 731-734. doi: 10.18805/lr.v0iOF.4481.
- Ataklı Bice, S., Şahin, S., Ceritoğlu, M. and Çağatay, H.F. (2022). Vermicompost enhances the effectiveness of arbuscular mycorrhizal fungi, cowpea development and nutrient Uptake. *Legume Research-An International Journal*. **45**(11): 1406-1413. doi: 10.18805/LRF-698.
- Bărdas, M., Rusu, T., Russu, F., Simon, A., Cean, F., Ceclan, O.A., Rezi, R., Popa, A. and Cărbunar, M.M. (2023). The impact of foliar fertilization on the physiological parameters, yield and quality indices of the soybean crop. *Agronomy*. **13**(5): 1287. <https://doi.org/10.3390/agronomy13051287>.
- Beyk-Khormizi, A., Sarafriz-Ardakani, M.R., Hosseini Sarghein, S., Moshtaghioun, S.M., Mousavi-Kouhi, S.M. and Taghavizadeh Yazdi, M.E. (2023). Effect of organic fertilizer on the growth and physiological parameters of a traditional medicinal plant under salinity stress conditions. *Horticulturae*. **9**(6): 701.
- Blount, A.R., Wright, D.L. and Sprenkel, R.K. (2017). Forage soybean production systems. *Agronomy Journal*. **109**: 246-255.
- Board, J.E. and Modali, H. (2005). Soybean yield and leaf area index. *Crop Science*. **45**: 1194-1202.
- Choudhary, C.S., Nongmaithem, D., Singh, A.P., Choudhary, S., Solo, V. and Karak, T. (2025). Effect of phosphorus levels and biofertilizers on the growth and yield of summer black gram (*Phaseolus mungo* L.). *Legume Research-An International Journal*. **48**(1): 167-171. doi: 10.18805/LR-5354.
- Colla, G. and Rouphael, Y. (2015). Biostimulants in horticulture. *Scientia Horticulturae*. **196**: 1-14.
- Easlon, H.M. and Bloom, A.J. (2014). Easy leaf area: Automated leaf area measurement. *Applications in Plant Sciences*. **2**: 1400033.
- FAO. (2017). The Future of Food and Agriculture-Trends and Challenges. Food and Agriculture Organization of the United Nations, Rome.
- Ferreira, A.S., Zucareli, C., Fonseca, I.C.D.B., Shimizu, G.D., Werner, F., Zeffa, D.M. and Balbinot Junior, A.A. (2024). Leaf area index and light interception relationship with seed yield of soybean cultivars under reduced seeding rates. PREPRINT (Version 1) available at Research Square [<https://doi.org/10.21203/rs.3.rs-2587282/v1>]. pp 1639-1664.
- Glala, A.A., Hassan, A.A. and Abdel-Fattah, M.A. (2013). Sustainable fertilization strategies in crop production. *African Journal of Agricultural Research*. **8**: 1121-1129.
- Iqbal, A., Khan, R., Hussain, Q., Imran, M., Mo, Z., Hua, T. and Tang, X. (2024). Vermicompost application enhances soil health and plant physiological and antioxidant defense to conferring heavy metals tolerance in fragrant rice. *Frontiers in Sustainable Food Systems*. **8**: 1418554.
- Kocira, S., Szparaga, A., Kocira, A., Czerwińska, E., Depo, K., Erlichowska, B. and Deszcz, E. (2018). Effect of applying a biostimulant containing seaweed and amino acids on the content of fiber fractions in three soybean cultivars. *Legume Research*. **42**(3): 341-347. doi: 10.18805/LR-412.

- Kumar, N.V., Patil, M.B., Nadagouda, B.T., Beerge, R. and Rani, C.S. (2024). Effect of different organic sources on growth and seed quality parameters of black gram [*Vigna mungo* (L.) Hepper]. *Legume Research- An International Journal*. **47(11)**: 1981-1985. doi: 10.18805/LR-4793.
- Li, C., Wang, P., Lombi, E., Cheng, M., Tang, C., Howard, D.L., Menzies, N.W. and Kopittke, P.M. (2018). Absorption of foliar-applied Zn fertilizers by trichomes in soybean and tomato. *Journal of Experimental Botany*. **69(10)**: 2717-2729. <https://doi.org/10.1093/jxb/ery085>.
- Liu, X., Zhang, Y. and Han, W. (2021). Impacts of long-term fertilizer use on soil health. *Soil Biology and Biochemistry*. **153**: 108109.
- Meneguzzo, M.R.R., Meneghello, G.E., Nadal, A.P., Xavier, F.M., Dellagostin, S.M., Carvalho, I.R., Gonçalves, V.P., Lautenchleger, F. and Lângaro, N.C. (2021). Seedling length and soybean seed vigor. *Ciência Rural*. **51(7)**: e20190495. <https://doi.org/10.1590/0103-8478cr20190495>.
- Prasad, R. and Shivay, Y.S. (2020). Integrated nutrient management. *Indian Journal of Fertilisers*. **16**: 112-124.
- Qin, P., Song, W. and Yang, Z. (2022). Soybean as a global protein source. *Frontiers in Plant Science*. **13**: 845931.
- Rajasekar, M., Kumar, S. and Karunakaran, R. (2017). Foliar fertilization for sustainable agriculture. *International Journal of Plant and Soil Science*. **15**: 1-9.
- Safdar, M.E., Aziz, A. and Farooq, M. (2023). Global livestock production trends and challenges. *Sustainability*. **15**: 4372.
- Schjørring, J.K. and Cakmak, I. (2014). Plant nutrition and sustainable agriculture. *Plant and Soil*. **382**: 1-5.
- Shukla, P.S., Mantin, E.G. and Adil, M. (2019). Seaweed biostimulants and crop productivity. *Frontiers in Plant Science*. **10**: 1323.
- Shukla, P.S., Mantin, E.G. and Adil, M. (2021). Seaweed-based biostimulants and yield formation. *Plant Physiology and Biochemistry*. **166**: 676-689.
- Singh, M., Singh, V.P. and Reddy, K.S. (2013). Effect of foliar nutrition on crop productivity. *Indian Journal of Fertilisers*. **9**: 54-60.
- Sohail, A., Ahmed, U., Khan, R.A., Khan, M.H.A., Ikramullah, Iqbal, A., Adil, M., Bacha, U., Ahmad, S. and Abdullah. (2025). Application of humic acid and foliar sulfur positively affect yield and related attributes of soybean under the agroclimatic region of Peshawar Pakistan. *Pure and Applied Biology*. **14(1)**: 8-20. <http://dx.doi.org/10.19045/bspab.2025.140002>.
- Vishwanatha, S., Shwetha, B.N., Koppalkar, B.G., Ashoka, N., Ananda, N., Umesh, M.R. and Naik, V.S. (2022). Response of blackgram (*Vigna mungo* L.) and soybean (*Glycine max* L.) to novel bio stimulants in north eastern dry zone of Karnataka. *Legume Research-An International Journal*. **45(9)**: 1130-1136. doi: 10.18805/LR-4858.
- Wang, Y., Zhang, X. and Huang, C. (2020). Environmental risks of excessive chemical fertilizer application. *Agriculture, Ecosystems and Environment*. **293**: 106869.
- Watson, D.J. (1947). Comparative physiological studies on growth of field crops. *Annals of Botany*. **11**: 41-76.
- Xu, Y., Gao, Q., Xue, L., Zhang, J. and Wang, C. (2025). Optimized nitrogen fertilizer management enhances soybean [*Glycine max* (L.) Merril.] yield and nitrogen use efficiency by promoting symbiotic nitrogen fixation capacity. *Frontiers in Plant Science*. **16**: 1604251. <https://doi.org/10.3389/fpls.2025.1604251>.
- Zhang, J., Wang, X. and Zhao, Y. (2015). Global status of forage legumes. *Grassland Science*. **61**: 125-134.
- Zulfiqar, F., Casadesús, A and Brockman, H. (2020). Role of biostimulants in sustainable agriculture. *Agronomy*. **10**: 1969.