SIEMBRA
REVISTA DE CIENCIAS DE LA VIDA

Original Artícle

Synergy between biological and synthetic inputs: optimizing plant nutrition and improving rice (*Oryza sativa* L.) yield

Sinergia de insumos biológicos y sintéticos: optimización de la nutrición vegetal y mejora del rendimiento en arroz (*Oryza sativa* L.)

Christian Alejandro Durán Mera[1], Tania Damiana Villafuerte Ortiz [2], María Leticia Vivas Vivas[1], Eison Wilfrido Valdiviezo Freire[1], Milton Senen Barcos Arias[1], Jaime Alberto Naranjo Morán[3]

Siembra 13 (1) (2026): e8788
DOI: 10.29166/siembra.v13i1.8788

Received: 23/09/2025
Revised: 01/10/2025 / 30/03/2026
Acepted: 04/05/2026

Check for updates

[1] Universidad de Guayaquil. Facultad de Ciencias Agrarias. Av. Las Aguas y Juan Tanca Marengo. C.P. 090505. Guayaquil, Guayas, Ecuador.
[2] Asesora independiente. Km 30 vía Daule, Comuna Petrillo. 091901. Daule, Guayas, Ecuador.
[3] Universidad Politécnica Salesiana, Grupo de Investigación en Aplicaciones Biotecnológicas [GIAB], Carrera de Biotecnología. Campus María Auxiliadora, km 19,5 Vía a La Costa. Código Postal 090901. Guayaquil, Ecuador.

Correspondence: christian.duranm@ug.edu.ec

Abstract

Agricultural bio-inputs offer multiple benefits, such as improving soil texture, maintaining moisture and aeration for the root system, promoting the development of beneficial microorganisms, and enhancing crop nutrition. This research, conducted between November 2022 and February 2023 at the Petrillo site, Nobol canton, Guayas province, Ecuador, aimed to evaluate the effect of three bio-inputs (mycorrhizae, seaweed extracts, and efficient microorganisms) on the morphology and yield of rice. A randomized complete block design was used, with five treatments and three replicates. The data were analyzed using analysis of variance [ANOVA], and the means were compared using Tukey's test ($p \leq 0.05$). Variables evaluated included plant height (cm), number of tillers and panicles, panicle length (cm), grains per panicle, days to flowering and maturity, and grain yield (kg ha^{-1}). The results showed that the mycorrhizal treatment at 1 L ha^{-1} produced a significant positive effect on crop morphology and yield, reaching an average of 5,407 kg ha^{-1}. This demonstrates that the soil application of agricultural bio-inputs generates a favorable response compared to the control and conventional fertilization, improving nutrient absorption and the productive performance of the rice crop.

Keywords: crop nutrition, efficient microorganisms, mycorrhizae, seaweed extract, soil management.

Resumen

Los bioinsumos agrícolas ofrecen múltiples beneficios, como la mejora de la textura del suelo, el mantenimiento de la humedad y la aireación para el sistema radicular, el fomento del desarrollo de microorganismos benéficos y la promoción de una mejor nutrición en los cultivos. Esta investigación, desarrollada entre noviembre de 2022 y febrero de 2023 en el recinto Petrillo, cantón Nobol, provincia del Guayas, Ecuador, tuvo como objetivo evaluar el efecto de tres bioinsumos (micorrizas, extractos de algas y microorganismos eficientes) sobre la morfología y el rendimiento del arroz. Se utilizó un diseño de bloques completos al azar, con cinco tratamientos y tres repeticiones. Los datos se analizaron mediante un análisis de varianza [ANOVA] y las medias se compararon con la prueba de Tukey ($p \leq 0{,}05$). Se evaluaron variables como: altura de planta (cm), número de macollos y de panículas, longitud de panículas (cm), granos por panícula, días a la floración y maduración, y rendimiento de grano (kg ha^{-1}). Los resultados mostraron que el tratamiento con micorrizas a 1 L ha^{-1} produjo un efecto positivo significativo en la morfología y el rendimiento del cultivo, alcanzando un promedio de 5.407 kg ha^{-1}.

SIEMBRA
https://revistadigital.uce.edu.ec/index.php/SIEMBRA
ISSN-e: 2477-8850
Frequency: half-yearly
vol. 13, issue 1, 2026
siembra.fag@uce.edu.ec

Esto evidencia que la aplicación edáfica de bioinsumos agrícolas genera una respuesta favorable en comparación con el testigo y la fertilización convencional, mejorando la absorción de nutrientes y el desempeño productivo del cultivo de arroz.

Palabras clave: extracto de algas, manejo de suelos, micorrizas, microorganismos eficientes, nutrición de cultivos.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important cereals worldwide and a fundamental component of the diet of billions of people (Lombeida García et al., 2022). However, the intensification of agricultural practices to meet growing demand has led to severe degradation of rice-growing soils. This deterioration, caused by the excessive use of synthetic fertilizers and pesticides, reduces soil organic matter, alters soil pH, and compromises long-term fertility (Ahmad Rizal et al., 2024). This poses a direct threat to the sustainability of rice production systems and food security (Deepana et al., 2021).

The intensification of rice production has led to the progressive degradation of rice-growing soils. This phenomenon has been exacerbated by the extensive use of agricultural machinery, pesticides, and fertilizers (Pozo Galves et al., 2017). Furthermore, the continuous practice of monoculture significantly affects the physicochemical properties of the soil and reduces microbial biomass, a key indicator of soil health and fertility (Kumawat et al., 2023).

The combination of agricultural bio-inputs with conventional fertilization optimizes nutrient uptake and maximizes crop productivity. While fertilizers provide readily available nutrients, bio-inputs improve nutrient availability and enhance soil microbiota. This synergy not only increases yield but also promotes the sustainability of agricultural systems by reducing dependence on chemical inputs and mitigating the negative effects of intensive practices (Naranjo-Morán et al., 2022).

Faced with the challenges of intensive agriculture, seaweed extracts have emerged as a sustainable alternative for improving soil health in rice systems. These biostimulants contribute to soil restructuring by increasing porosity and water retention capacity, thereby promoting aeration and root development. Furthermore, their bioactive compounds, such as phytohormones and nutrients, stimulate microbial activity, enhancing organic matter mineralization and the gradual availability of essential nutrients. The reduction of exchangeable sodium and the improvement of soil aggregate stability facilitate the recovery of degraded or saline soils, thus optimizing conditions for rice growth and productivity (Tahar et al., 2024).

Mycorrhizae are another key bio-input in rice systems. These symbiotic fungi colonize rice roots, increasing the root surface area and facilitating the uptake of essential nutrients such as phosphorus, nitrogen, and micronutrients (Begum et al., 2019). Their presence improves soil structure and porosity, enhances water retention, and stimulates microbial activity in the rhizosphere, thereby strengthening soil fertility. Furthermore, mycorrhizae increase crop resistance to abiotic and biotic stresses, promoting healthier growth and higher yields while reducing dependence on chemical fertilizers (Ruiz-Sánchez et al., 2015).

Effective microorganisms [EMs] are microbial consortia composed of photosynthetic bacteria, lactic acid bacteria, and yeasts that contribute to improving soil fertility and biological activity. Their application in rice paddies promotes organic matter decomposition, increases nutrient availability, and stimulates microbial activity in the rhizosphere. They also improve soil structure by increasing porosity and water retention capacity, resulting in better root development and greater nutrient uptake efficiency. These effects are reflected in more vigorous plants with greater tolerance to abiotic stress, as well as improved yield and grain quality (Lucas & Llerena, 2024; Jupri et al., 2019).

Given the above, the combined application of mycorrhizae, seaweed extracts, and effective microorganisms with conventional fertilization improves soil health, optimizes nutrient uptake, and increases rice productivity. Therefore, this study aims to evaluate the effect of these soil-applied bio-inputs on the morphological performance and yield of rice cultivation, establishing a sustainable and efficient alternative for intensive agricultural systems.

2. Materials and Methods

The research was conducted between November 2022 and February 2023 at the Petrillo site, located in Nobol Canton, Guayas Province, Ecuador. To determine soil fertility, samples were initially collected following the methodology described by Mendoza and Espinoza (2017). The samples were subsequently analyzed at the Water and Soil Department Laboratory of INIAP-Litoral Sur, using the methods described by Quezada Crespo et al. (2017) for data validation. The results obtained are presented in Table 1.

2.1. Experimental design

A randomized complete block design was used, consisting of five treatments and three replications, resulting in a total of 15 experimental units. Each unit measured 7 × 5 m (35 m²), with a total experimental area of 552 m². A random sample of ten plants per experimental unit was used to evaluate the agronomic variables, while the harvested net area (6 m²) was considered for yield determination. The data obtained were subjected to analysis of variance [ANOVA], and when significant differences among treatments were detected, means were compared using Tukey's test at a 5% probability level ($p < 0.05$) using InfoStat statistical software version 2020 (Table 2).

2.2. Experiment management

The genetic material used in the experiment was the 'SFL-11' rice variety, recognized for its high yield in the main rice-growing areas of Ecuador. This variety adapts to warm climates and well-drained soils and is characterized by its high productivity under irrigation (6–9 t ha^{-1}) and rainfed conditions (5–8.5 t ha^{-1}). Other outstanding agronomic characteristics include a vegetative cycle of 127 to 131 days and a plant height of 126 cm. Its phytosanitary profile includes moderate resistance to fungal diseases and pests, as well as high resistance to lodging (AGRIPAC, 2021).

The soil was prepared with three passes of a rototiller, followed by leveling. Transplanting was carried

Table 1. Soil fertility of the rice-growing study area.

Criterion	Unit	Result	Value
Texture	%	Sand: 14 Silt: 38 Clay: 48	Clayey
pH	PN	7.3	Practically neutral
Organic matter	%	3.8	Medium
NH4	ug ml^{-1}	23	Medium
P	ug ml^{-1}	19	Medium
K	meq 100 ml^{-1}	4.050	High
Ca	meq 100 ml^{-1}	1.184	High
Mg	meq 100 ml^{-1}	118	High
S	ug ml^{-1}	115	High
Zn	ug ml^{-1}	2.2	Medium
Cu	ug ml^{-1}	14.9	High
Fe	ug ml^{-1}	16	Low
Mn	ug ml^{-1}	24	High
B	ug ml^{-1}	0.18	Bajo

Table 2. Treatments evaluated in the research.

Treatments	Description	Doses
1	Control	No fertilization
2	CF*	N:170 kg ha^{-1} P_2O_5: 44 kg ha^{-1} K_2O: 190 kg ha^{-1}
3	Mycorrhizae + CF	1 L ha^{-1}
4	Seaweed extracts + CF	250 cc ha^{-1}
5	Effective microorganisms + CF	4 L ha^{-1}

* CF: Conventional fertilization

out when seedlings were 17 days old. Five seedlings were established per planting site, with a spacing of 0.25 m between plants and 0.25 m between rows. Weed control was performed manually.

The agricultural bio-inputs were applied to the soil through fractional drench applications. The first application was performed three days before transplanting, the second 13 days after transplanting, and the third 33 days after transplanting. The applied doses were as follows: mycorrhizae: first application (333 cc ha^{-1}), second application (333 cc ha^{-1}), and third application (334 cc ha^{-1}); seaweed extracts: first application (83 cc ha^{-1}), second application (83 cc ha^{-1}), and third application (84 cc ha^{-1}); effective microorganisms: first application (1.3 L ha^{-1}), second application (1.3 L ha^{-1}), and third application (1.4 L ha^{-1}). The composition of each bio-input is detailed in Table 3.

Conventional fertilization was carried out according to the results obtained from the soil analysis (Table 1) and following the methodology proposed by the International Plant Nutrition Institute (IPNI, 2016). The following fertilizer sources were used: urea, 192 kg ha^{-1}; diammonium phosphate [DAP], 22 kg ha^{-1}; and muriate of potash [KCl], 190 kg ha^{-1}. Fertilizers were applied manually and uniformly, considering the following nutrient splits: nitrogen [N], 50% at 15 days after transplanting and 50% at 35 days after transplanting; phosphorus [P], 100% at 7 days after transplanting; and potassium [K], 100% at 35 days after transplanting. Conventional fertilization served as the basis for treatments that included the application of agricultural bio-inputs.

Several pests and phytosanitary problems were observed and controlled through the application of insecticides and fungicides at specific doses. For the control of *Hydrellia* sp., thiamethoxam + lambda-cyhalothrin was applied at 0.125 L ha^{-1}, 19 days after transplanting [DAT]. For *Diatraea saccharalis*, the same insecticide and dose were used at 65 DAT. *Oebalus ornatus* was controlled with a soluble concentrated insecticide at 1.5 L ha^{-1}, applied at 77 DAT. Finally, *Pyricularia grisea* was managed with a fungicide composed of azoxystrobin and flutriafol at 1.25 L ha^{-1}, 57 DAT.

The crop was managed under a flood irrigation system, maintaining a water depth of 5–8 cm. Irrigation was applied every 5–6 days according to climatic conditions and the soil's water-holding capacity.

The crop was harvested at physiological maturity using a sickle, ensuring proper grain collection.

2.3. Variables evaluated

- Plant height (cm): Measured from ground level to the tip of the tallest panicle, excluding the awn, using a measuring tape.

Table 3. Composition of the agricultural bio-inputs used in the research.*

Bio-input	Composition	Concentration
Mycorrhizae	Endomycorrhizae (*Glomus* spp.)	8 x 1011 CFU L^{-1}
	Ectomycorrhizae (*Pisoltithus* spp y *Rhizopogon* spp.)	7 x 1011 CFU L^{-1}
Seaweed extracts	*Ascophyllum nodosum*	99,65% (p/p)
Effective microorganisms	*Trichoderma harzianum* (CT-22®), *Trichoderma viride*	2 x 10^8
	Potassium-solubilizing bacteria (*Bacillus subtilis*, *Bacillus pumilus*,*Clostridium* sp.)	1x 10^8
	Lactic acid bacteria (*Lactobacillus acidophillus*, L. *Casei*, L.*Paracasei*)	2 x 10^8
	Nitrifying bacteria (*Azotobacter* sp., *Streptomyces* sp., *Rhizobium* sp)	1 x 10^8
	Phosphorus-solubilizing bacteria (*Pseudomonas* sp., *Kocuria* sp., *Penicillium*)	1 x 10^8
	Fungi and yeasts (*Saccharomyces cerevisiae*, *Penicillium sp.*, *Paecilomyces lilacinus*)	3 x 10^9

* The composition, concentration, and biological activity of the bio-inputs utilized in the study were based on the technical specifications provided by the manufacturers (FENEC S.A., QSI Ecuador S.A., and Campo-Track®, respectively).

- Number of tillers per plant: The total number of tillers on each plant within the experimental unit was counted.
- Days to flowering: Determined from 70 days after transplanting until 50% flowering was reached in each experimental unit.
- Days to maturity: Determined from 80 days after transplanting, considering the light brown color of the grains and the absence of green coloration in the panicles as maturity criteria.
- Number of panicles: The number of panicles within 1 m² of each experimental unit was counted.
- Panicle length (cm): Measured from the panicle base (ciliary node) to the tip of the panicle, excluding the awn.
- Number of grains per panicle: Counted one day before harvest in the harvested area of each experimental unit.
- Grain yield (kg ha⁻¹): Determined from the harvested net area (6 m²) of each experimental unit and adjusted to 13% grain moisture using Equation [1], where *P*Aj = adjusted weight, *P*ac = sample weight, *H*ac = actual moisture content, and *H*d = desired moisture content.

$$P\ Aj\left(\frac{kg}{ha}\right)=\frac{Pac\ x\ (100-Hac)}{100-Hd}x\frac{10.000m^2}{\text{Net area}} \quad [1]$$

3. Results

ANOVA demonstrated high statistical significance ($p < 0.0001$**) among treatments for all evaluated variables: plant height, number of tillers per plant, days to flowering, and days to crop maturity.

According to the results of Tukey's test (Figure 1), the greatest plant height was obtained with the Mycorrhizae + CF and Algal Extract + CF treatments, which reached an average of 124 cm. Regarding the number of tillers, the Mycorrhizae + CF treatment was statistically superior, achieving an average of 25.77 tillers per plant. With respect to the crop cycle, the Effective Microorganisms + CF treatment resulted in later flowering, with an average of 81 days. Consistently, the Algal Extract + CF and Effective Microorganisms + CF treatments extended the cycle to maturity to 102 and 103 days, respectively. It is worth noting that the treatment with Mycorrhizae + CF showed an intermediate effect, maturing in 99 days.

ANOVA revealed highly significant differences ($p < 0.0001$) among treatments for the number of panicles, number of grains per panicle, and grain yield (kg ha⁻¹). Likewise, panicle length showed significant differences ($p = 0.0106$).

According to Tukey's test (Figure 2), the Mycorrhizae + CF treatment produced the highest number of panicles, with an average of 23.00, and the highest grain yield, reaching 5,407 kg ha⁻¹. In contrast, the Seaweed Extract + CF treatment recorded the highest number of grains per panicle and the greatest panicle length, with 137 grains and 28.01 cm, respectively.

4. Discussion

Analysis of the results revealed that the incorporation of agricultural bio-inputs combined with conventional fertilization significantly improved rice productivity. These findings indicate that, although conventional fertilization enhances crop performance, the addition of biological inputs optimizes plant growth, yield components, and, consequently, grain yield.

Regarding plant height, the Mycorrhizae + CF and Seaweed Extract + CF treatments promoted vigorous growth, reaching an average height of 124 cm. Mycorrhizal symbiosis improves nutrient uptake, increasing vegetative vigor (Guigard et al., 2023), while seaweed extracts, rich in phytohormones, stimulate cell elongation and root development, promoting plant growth and productivity (Thaimei et al., 2024). This value exceeds that reported by Meza Aguilar & Almeida Veintimilla (2024), who applied 10.91 kg ha⁻¹ of seaweed extract (*Ascophyllum nodosum*) to the 'INIAP FL-1480' variety and obtained an average plant height of 99 cm.

About the number of tillers per plant, the Mycorrhizae + CF treatment achieved the highest average (25.77), demonstrating the positive effect of inoculation on rice vegetative development. This suggests that mycorrhizal symbiosis enhances nutrient uptake and overall plant growth. Ibrahim et al. (2024) reported that mycorrhizal application increased the maximum number of productive tillers in rice, establishing a direct relationship between fungal inoculation and tillering capacity. Furthermore, these values exceed those reported by Cordero Flores & Manzaneda Delgado (2021), who evaluated six rice varieties under irrigation and obtained an average of 11.00 tillers in the 'EPAGRI-109' cultivar during the dry season.

Regarding days to flowering, the Effective Microorganisms + CF treatment showed the highest average (81.00 days), indicating that inoculation influenced the rice phenological cycle. This finding agrees with Demir et al. (2024), who reported that the application of compost enriched with effective microorganisms improved soil fertility and rice agronomic characteristics, which may be associated with changes in flowering time.

Regarding days to maturity, the Mycorrhizae + CF

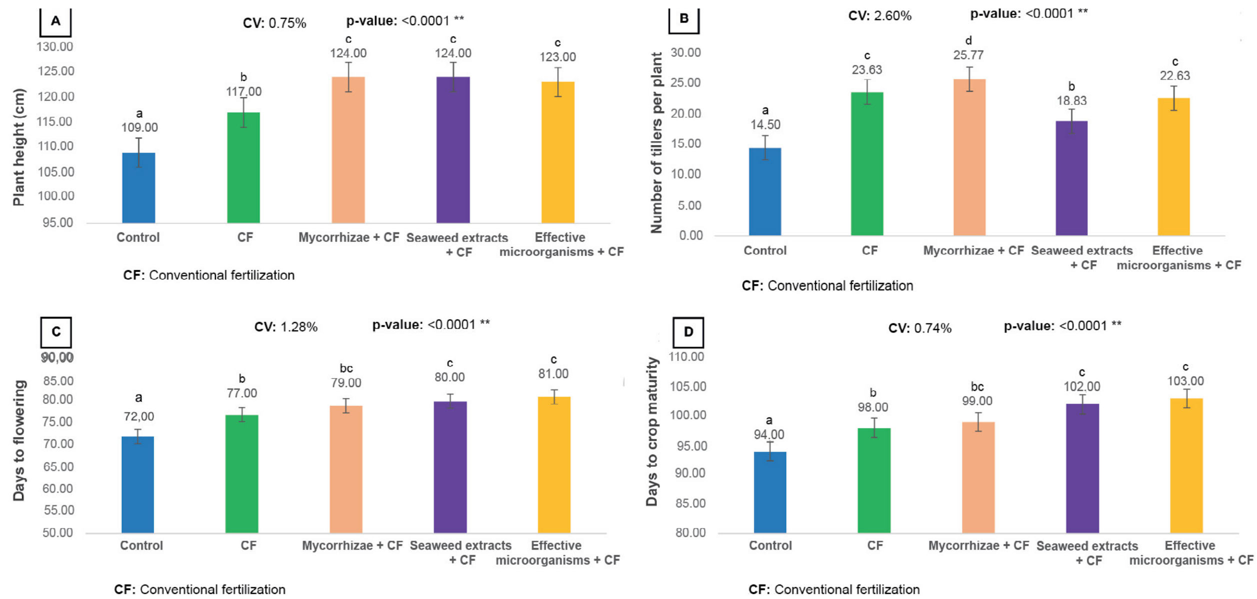

Figure 1. Average plant height (cm) (A), number of tillers per plant (B), days to flowering (C), and days to crop maturity (D) as a function of the application of agricultural bio-inputs. Means with different letters differ statistically according to Tukey's test ($p \leq 0.05$).

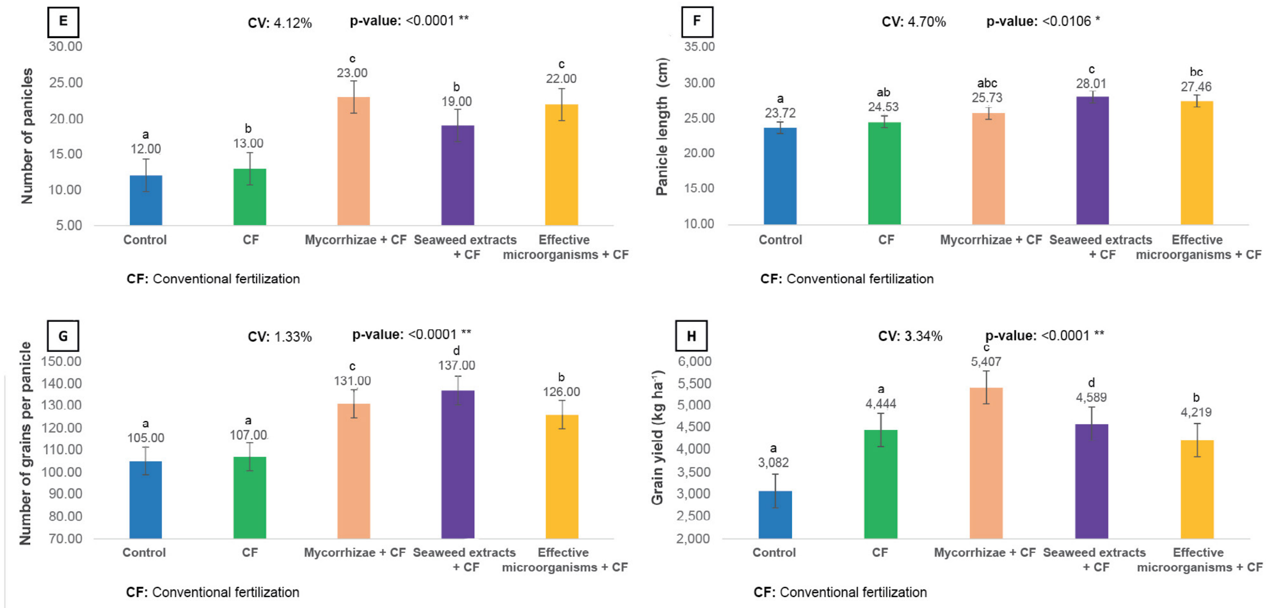

Figure 2. Average values for the number of panicles (E), (F), number of grains per panicle (G), and grain yield (kg ha^{-1}) (H) as a function of the application of agricultural bio-inputs. Means with different letters are statistically different according to Tukey's test ($p \leq 0.05$).

treatment showed an intermediate response, with an average of 99 days. This suggests that combining mycorrhizae with conventional fertilization can influence the synchronization of the rice phenological cycle by balancing vegetative growth and reproductive development. Mulyadi and Jiang (2023) reported that the combined application of mycorrhizae and nitrogen fertilization accelerated flowering in rice, demonstrating that this interaction can modify crop maturity. Likewise, Suárez Baque and Durán Mera (2023), evaluating the 'SFL-11' variety under conventional fertilization, reported maturity at 96 days, similar to the results obtained in this study. This confirms that this variety consistently fulfils its genetic potential.

The Mycorrhizae + CF treatment produced the highest number of panicles, with an average of 23.00, demonstrating the effectiveness of mycorrhizal symbiosis in improving rice reproductive performance. This agrees with Martín-Cardoso et al. (2025), who reported that arbuscular mycorrhizal fungi increase plant height and vigor, and promote panicle formation by improving phosphorus and nitrogen uptake. Furthermore, this value exceeds that reported by Hernández Quiñónez et al. (2021), who obtained an average of 12.24 panicles per plant using conventional NPK fertilization supplemented with micronutrients (Ca, Mg, S, Fe, Mn, Cu, Zn, Cl, B, Mo) and foliar silicon.

For panicle length, the Seaweed Extract + CF treatment reached the highest value, with an average of 28.01 cm. This exceeds the result reported by Ruiz Parrales et al. (2020), who obtained an average panicle length of 21.00 cm in the 'INIAP-15' variety under N: 160 kg ha^{-1}, K_2O: 90 kg ha^{-1} y Zn: 2 L ha^{-1} fertilization. Similarly, Calero Hurtado et al. (2020) reported an average panicle length of 27.00 cm using effective microorganisms at a planting density of 35,000 plants ha^{-1} and soil application of 100 mL L^{-1} and 40 L ha^{-1}. Taken together, these results support the effectiveness of seaweed extracts in promoting rice reproductive development. This finding is consistent with recent studies reporting significant improvements in panicle length associated with the use of biostimulants.

Regarding the number of grains per panicle, the Seaweed Extract + CF treatment achieved the highest average (137.00 grains), demonstrating the positive effect of this biostimulant on rice fertility. This result agrees with Thamvithayakorn et al. (2024), who reported that *Ascophyllum nodosum* extracts combined with plant growth-promoting bacteria significantly increased the number of grains per panicle. This increase is due to the stimulation of cell elongation and hormonal activity, which promote the development of reproductive organs. Furthermore, this value exceeds that reported by González Pita and Painii Montero (2022), who obtained an average of 129.00 grains per panicle using seaweed-based foliar biostimulants at a dose of 1 L ha^{-1}. This highlights the greater efficacy of the treatment used in this study.

Finally, the Mycorrhizae + CF treatment produced the highest grain yield, reaching 5,407 kg ha^{-1}, demonstrating its effectiveness in improving rice productivity. This result agrees with Das et al. (2022), who reported that mycorrhizal inoculation combined with phosphorus fertilization significantly increased grain yield by improving nutrient uptake and water use efficiency under alternate-day irrigation. It also exceeds the yield reported by Diaz and Contreras (2022), who obtained 4,450 kg ha^{-1} in the 'Paddy' variety using 10% humic acids in Nobol, Ecuador. As well as the results reported by Zuñiga et al. (2020), who evaluated the use of natural zeolite plus basic fertilizer on the "PALMAR-18" variety, achieving a yield of 2,550 kg ha^{-1}. These findings suggest that mycorrhizae are an effective strategy for enhancing

5. Conclusions

It is concluded that the application of bio-inputs combined with conventional fertilization is an effective strategy for improving rice productivity. The Mycorrhizae + CF treatment enhanced tiller and panicle development, resulting in the highest grain yield (5,407 kg ha^{-1}). Although Seaweed Extract + CF and Effective Microorganisms + CF improved specific agronomic traits, the mycorrhizae-based treatment showed the best overall performance. These findings suggest that integrating bio-inputs with conventional fertilization is a sustainable strategy for optimizing rice production.

Acknowledgments

The authors thank the Faculty of Agricultural Sciences at the University of Guayaquil, as well as the field and laboratory staff, for their support during the development of this study.

Contributor roles

- Christian Alejandro Durán Mera: conceptualization, data curation, supervision, project administration, writing – original draft.
- Tania Damiana Villafuerte Ortiz: resources, funding acquisition.
- María Leticia Vivas Vivas: conceptualization, writing – original draft.
- Eison Wilfrido Valdiviezo Freire: formal analysis, software.
- Milton Senén Barcos Arias: visualization, writing – original draft.
- Jaime Alberto Naranjo Morán: supervision, writing – review & editing.

Data Availability

Data will be made available on request.

Use of Artificial Intelligence

The authors declare that no artificial intelligence has been used in the preparation of the manuscript.

Ethical Implications

The authors declare that there are no ethical implications.

Conflict of Interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

References

AGRIPAC. (2021). Semillas AGRIPAC-Arroz. https://agripac.com.ec/productos/arroz-sfl-11-bioactivado/

Ahmad Rizal, A. R., Md Nordin, S., Abd Rashid, R., & Hassim, N. (2024). Decoding the complexity of sustainable rice farming: A systematic review of critical determining factor of farmers' sustainable practices adoption. *Cogent Food & Agriculture*, *10*(1), 2334994. https://doi.org/10.1080/23311932.2024.2334994

Begum, N., Qin, C., Ahanger, M. A., Raza, S., Khan, M. I., Ashraf, M., Ahmed, N., & Zhang, L. (2019). Role of arbuscular mycorrhizal fungi in plant growth regulation: Implications in abiotic stress tolerance. *Frontiers in Plant Science, 10*, 1068. https://doi.org/10.3389/fpls.2019.01068

Calero Hurtado, A., Olivera Viciedo, D., Pérez Díaz, Y., González-Pardo Hurtado, Y., Yánez Simón, L. A., & Peña Calzada, K. (2020). Manejo de diferentes densidades de plantación y aplicación de microorganismos eficientes incrementan la productividad del arroz. *Idesia (Arica)*, *38*(2), 109–117. https://doi.org/10.4067/S0718-34292020000200109

Cordero Flores, P., & Manzaneda Delgado, F. (2021). Evaluación agronómica de seis variedades de arroz (*Oryza sativa* L.) sembradas en dos épocas bajo riego, en el municipio de San Buenaventura, Bolivia. *Revista de Investigación e Innovación Agropecuaria y de Recursos Naturales*, *8*(1), 7–16. https://doi.org/10.53287/xivu8492oe20n

Das, D., Ullah, H., Himanshu, S. K., Tisarum, R., Cha-um, S., & Datta, A. (2022). Arbuscular mycorrhizal fungi inoculation and phosphorus application improve growth, physiological traits, and grain yield of rice under alternate wetting and drying irrigation. *Journal of Plant Physiology*, *278*, 153829. https://doi.org/10.1016/j.jplph.2022.153829

Deepana, P., Bama, K. S., Santhy, P., & Devi, T. S. (2021). Effect of seaweed extract on rice (*Oryza sativa* var. ADT53) productivity and soil fertility in Cauvery delta zone of Tamil Nadu, India. *Journal of Applied and Natural Science*, *13*(3), 1111–1120. https://doi.org/10.31018/jans.v13i3.2906

Demir, H., Saka, A. K., Uçan, U., Akgün, İ. H., & Yalçı, H. K. (2024). Impact of effective micro-organisms (EM) on the yield, growth and bio-chemical properties of lettuce when applied to soil and leaves. *BMC Plant Biology*, *24*(1), 1-12. https://doi.org/10.1186/s12870-024-05980-y

Diaz, Y., & Contreras, J. (2022). Response of rice *(Oryza sativa L.)* crop to the application of biol, manure tea and humic acid. *Manglar*, *19*(1), 85–90. https://doi.org/10.17268/manglar.2022.011

González Pita, A. de J., & Painii Montero, V. F. (2022). Influencia de bioestimulantes foliares a base de algas marinas, sobre el desarrollo y rendimiento del cultivo de arroz en Daule, Ecuador. *ECOAgropecuaria. Revista Científica Ecológica Agropecuaria*, *1*(1), 1–6. https://doi.org/10.53591/recoa.v1i1.682

Guigard, L., Jobert, L., Busset, N., Moulin, L., & Czernic, P. (2023). Symbiotic compatibility between rice cultivars and arbuscular mycorrhizal fungi genotypes affects rice growth and mycorrhiza-induced resistance. *Frontiers in Plant Science*, *14*, 1278990. https://doi.org/10.3389/fpls.2023.1278990

Hernández Quiñónez, J. A., Salazar Mercado, S. A., & Rodríguez Araújo, E. A. (2021). Efecto de los elementos menores en la calidad molinera del arroz (*Oryza sativa* L.) variedad F-2000. *Revista Mutis*, *11*(1), 8–21. https://doi.org/10.21789/22561498.1711

Ibrahim, M., Abdulhameed, A., Nayaya, A. J., & Ezra, A. G. (2024). Effect of Arbuscular Mycorrhizal Fungi on the growth and Yield of Rice (*Oryza sativa* L.) in Bauchi, Nigeria. *Journal of Global Ecology and Environment*, *20*(3), 1–12. https://doi.org/10.56557/jogee/2024/v20i38797

International Plant Nutrition Institute [IPNI]. (2016). Requerimientos nutricionales de los cultivos- Arroz. IPNI. https://aws.agroconsultasonline.com/documento.html?op=d&documento_id=163

Jupri, A., Fanani, R. A., Syafitri, S. M., Mayshara, S., Nurijawati, Pebriani, S. A., & Sunarpi, H. (2019). Growth and yield of rice plants sprayed with *Sargassum polycystum* extracted with different of concentration. *AIP Conference Proceedings*, *2199*(1), 070009. https://doi.org/10.1063/1.5141323

Kumawat, A., Kumar, D., Shivay, Y. S., Bhatia, A., Rashmi, I., Yadav, D., & Kumar, A. (2023). Long-term impact of biofertilization on soil health and nutritional quality of organic basmati rice in a typic ustchrept soil of India. *Frontiers in Environmental Science*, *11*, 1031844. https://doi.org/10.3389/fenvs.2023.1031844

Lombeida García, E. D., Medina Litardo, R., Uvidia Vélez, M., & Pazmiño Pérez, Á. (2022). Caracterización de un sistema de producción de arroz (*Oriza sativa* L.) en el cantón Babahoyo. *Revista Científica y Tecnológica UPSE*, *9*(2), 39–47. https://doi.org/10.26423/rctu.v9i2.686

Lucas, J., & Llerena, L. (2024). *Microorganismos benéficos como biofertilizantes eficientes en el cultivo del arroz (Oryza sativa L.)*. Universidad Técnica Estatal de Quevedo. https://repositorio.uteq.edu.ec/handle/43000/7212

Martín-Cardoso, H., Castillo, L., Busturia, I., Bücker, G., Marqués, L., Pla, E., Català-Forner, M., Domingo, C., & San Segundo, B. (2025). Arbuscular mycorrhizal fungi increase blast resistance and grain yield in japonica rice cultivars in flooded fields. *Rice*, *18*(1), 47. https://doi.org/10.1186/s12284-025-00805-4

Mendoza, B. R., & Espinoza, A. (2017). *Guía técnica para muestreo de suelos*. Universidad Nacional Agraria y Catholic Relief Services. https://repositorio.una.edu.ni/id/eprint/3613

Meza Aguilar, J. J., & Almeida Veintimilla, A. C. (2024). Efecto de algas marinas como fertilizante para el cultivo de arroz (*Oryza sativa* L) en Babahoyo, Ecuador. *ECOAgropecuaria. Revista Científica Ecológica Agropecuaria*, *1*(2), 6-12. https://doi.org/10.53591/recoa.v1i2.320

Mulyadi, & Jiang, L. (2023). The combined application of biochar and arbuscular mycorrhizal fungi (AMF) enhanced the physical and chemical properties of soil and rice productivity in Indonesia. *Sustainability*, *15*(12), 9782. https://doi.org/10.3390/su15129782

Naranjo-Moran, J. A., Mora-González, A. F., Moina-Quimí, E., Ruíz-Barzola, O., Alvarado-Cadena, O., Calle-Delgado, P., Flores-Cedeño, J., Oviedo-Anchundia, J., & Senen Barcos-Arias, M. (2022). Comportamiento en la absorción de Na y Pb en plantas de cucurbitáceas e inoculación de micorrizas arbusculares nativas en especie tolerante y suceptible. *Revista Internacional de Contaminación Ambiental*, *38*, 407–421. https://doi.org/10.20937/RICA.54023

Pozo Galves, C., Cabrera Alonso, J. R., Márquez Reina, E., Hernández Hernández, O., Ruiz Sanchez, M., & Domínguez Palacio, D. (2017). Characteristics and classification of Ferruginous Nodular Gley soils under intensive rice crop production from Los Palacios. *Cultivos tropicales*, *38*(4), 58-64. http://scielo.sld.cu/pdf/ctr/v38n4/ctr11417.pdf

Quezada Crespo, C. J., Carrillo Zenteno, M. D., Morales Intriago, F. L., & Carrillo Alvarado, R. A. (2017). Nutrient critical levels and availability in soils cultivated with peach palm (*Bactris gasipaes* Kunth.) in Santo Domingo de Los Tsáchilas, Ecuador. *Acta Agronómica*, *66*(2), 235-240. https://doi.org/10.15446/acag.v66n2.55026

Ruiz Parrales, Y. G., Sánchez Vásquez, V. L., López Izurieta, M. D., & Molina Barbotó, V. (2020). Fertilización química basada en análisis de suelo en dos líneas promisorias de arroz. *Magazine De Las Ciencias: Revista de Investigación e Innovación*, *5*(7), 56–72. https://revistas.utb.edu.ec/index.php/magazine/article/view/927/683

Ruiz-Sánchez, M., Santana Baños, Y., Muñoz Hernández, Y., Martínez Robaina, A. Y., & Bharat, B. V. (2015). Simbiosis de micorrizas arbusculares en plantas de arroz (*Oryza sativa* L.) en condiciones de inundación y secano. *Acta Agronómica*, *64*(3), 227–233. https://doi.org/10.15446/acag.v64n3.43087

Suárez Baque, D. L., & Durán Mera, C. A. (2023). Aplicación de herbicidas postemergentes para el control de malezas en el cultivo de arroz (*Oryza sativa* L.). *Revista Científica Ecológica Agropecuaria RECOA*, *2*(1), 1-9. https://revistas.ug.edu.ec/index.php/recoa/article/view/2189/3147

Tahar, S. Z. A., Surugau, N., Eng, H. S., Tan, W.-H., & Sam, L. M. (2024). Biostimulant effects of brown seaweed extract (*Sargassum polycystum*) on the growth and yield of pigmented upland rice (*Oryza sativa* cv Tadong). *Tropical Open Soil and Land Journal*, *11*(2), 51-64. https://tost.unise.org/pdfs/vol11/no2/ToST-11x2x51-64xOA.pdf

Thaimei, T., Bokado, K., & Bera, B. B. (2024). Seaweed Extract for Sustainable Rice Production- A Review. *International Journal of Plant & Soil Science*, *36*(7), 147–160. https://doi.org/10.9734/ijpss/2024/v36i74716

Thamvithayakorn, P., Phosri, C., Robinson-Boyer, L., Limnonthakul, P., Doonan, J. H., & Suwannasai, N. (2024). The synergistic impact of a novel plant growth-promoting rhizobacterial consortium and ascophyllum nodosum seaweed extract on rhizosphere microbiome dynamics and growth enhancement in *Oryza sativa* L. RD79. *Agronomy*, *14*(11), 2698. https://doi.org/10.3390/agronomy14112698

Zuñiga Orozco, A., Montero Jara, K., & Peña Cordero, W. (2020). Análisis de la eficiencia de la fertilización mediante el uso de Zeolita natural y Mucuna pruriens en el cultivo de arroz (*Oryza sativa* L.) bajo condiciones controladas en microparcelas situadas en Parrita, Puntarenas, Costa Rica. *Repertorio Científico*, *23*(2), 23–36. https://doi.org/10.22458/rc.v23i2.2985