



Seasonal dynamics and efficiency of capture systems for the isolation of native soil microorganisms under tropical conditions in El Carmen, Ecuador

Dinámica estacional y eficiencia de sistemas de captura para el aislamiento de microorganismos autóctonos del suelo tropical en El Carmen, Ecuador

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Abstract

This study evaluated seasonal dynamics and the efficiency of different capture systems for isolating functional native microorganisms from tropical soil in El Carmen, Ecuador. A factorial design integrating trap type, substrate type, locality, and season (dry and rainy) was implemented, and phosphate-solubilizing microorganisms, nitrogen-fixing bacteria, actinomycetes, and cellulolytic microorganisms were quantified. Capture efficiency was significantly influenced by interactions among the experimental factors. For phosphate-solubilizing microorganisms, the canister-liquid substrate combination reached the highest value (2.57×10^3 CFU g⁻¹), whereas during the dry season the performance pattern varied according to the matrix used. For actinomycetes, the tub-type trap consistently produced the highest counts, reaching up to 3.0×10^8 CFU g⁻¹, which indicated greater microenvironmental stability within the system. For cellulolytic microorganisms, although the liquid substrate yielded higher mean values, no robust statistical differences were detected among most treatments. The rainy season also recorded a higher overall mean (2.31×10^6 CFU g⁻¹) than the dry season (1.69×10^6 CFU g⁻¹), confirming the determining role of water availability in microbial activity. Capture-system architecture, its interaction with substrate type, and seasonality are therefore key factors for optimizing the isolation of functional microorganisms from tropical soils, providing a methodological basis for microbial bioprospecting and the development of agricultural bioinputs.

Keywords: microbiology, isolation, functional bacteria, dynamics, soils.

Resumen

El estudio tuvo como objetivo evaluar la dinámica estacional y la eficiencia de distintos sistemas de captura para el aislamiento de microorganismos autóctonos funcionales en suelo tropical de El Carmen, Ecuador. Se implementó un diseño factorial que integró tipo de trampa, tipo de sustrato, localidad y época (seca y lluviosa), y se cuantificaron microorganismos solubilizadores de fósforo, fijadores de nitrógeno, actinomicetos y microorganismos celulolíticos. Los resultados evidenciaron que la eficiencia de captura fue significativamente influenciada por la interacción entre factores experimentales. En microorganismos solubilizadores de fósforo, la combinación canecas-sustrato líquido alcanzó el mayor valor ($2,57 \times 10^3$ UFC g⁻¹), mientras que en época seca el patrón de desempeño varió según la matriz empleada. Para actinomicetos, la trampa tipo tarrina presentó consistentemente los mayores recuentos, alcanzando hasta $3,0 \times 10^8$ UFC g⁻¹, lo que indicó mayor estabilidad microambiental del sistema. En microorganismos celulolíticos, aunque el sustrato líquido mostró promedios superiores, no se detectaron diferencias estadísticas entre la mayoría de los tratamientos. Asimismo, la época lluviosa registró un promedio general mayor ($2,31 \times 10^6$ UFC g⁻¹) en comparación con la época seca ($1,69 \times 10^6$ UFC g⁻¹), confirmando el efecto determinante de la disponibilidad hídrica en la actividad microbiana. Se concluye que la arquitectura del sistema de captura, su interacción con el sustrato y la estacionalidad constituyen factores clave para optimizar el aislamiento de microorganismos funcionales en suelos tropicales, aportando fundamentos metodológicos para programas de bioprospección y desarrollo de bioinsumos agrícolas.

Palabras clave: microbiología, aislamiento, bacterias funcionales, dinámica, suelos.



Introduction

Modern agriculture faces the challenge of optimizing sustainable production to ensure global food security under climate-change scenarios. Changes in precipitation regimes, the increasing frequency of extreme events such as droughts and floods, and the sustained rise in temperature have intensified environmental stress on crops and agricultural soils (Alarcón et al., 2020). This problem is compounded by the intensive use of agrochemicals to maximize yields, a practice that has adversely affected soil structure, fertility, and biodiversity and compromised long-term functional capacity. In this context, developing innovative strategies that maintain agricultural productivity without further degrading natural resources has become imperative (De Souza et al., 2020).

Soil is a complex biological system in which microorganisms play a decisive role in decomposition and nutrient recycling. Bacteria, fungi, and actinomycetes transform complex organic compounds into mineral forms available to plants, regulate essential biogeochemical cycles, and sustain primary productivity (Trivedi et al., 2021; Khmelevtsova et al., 2022). Microbial respiration, nutrient mineralization, and the formation of soil biostructures are key processes for ecological stability and agroecosystem resilience (Adeleke and Babalola, 2021). Consequently, soil-microbiome dynamics are recognized as a structural component of soil health and terrestrial-ecosystem functioning.

Anthropogenic activities such as deforestation associated with agricultural expansion, mining, and land-use change have profoundly altered ecosystem structure and function (Saad et al., 2020; Iquebal et al., 2022). These transformations have promoted the loss of microbial biodiversity and weakened natural nutrient-recycling mechanisms, increasing soil vulnerability to degradation (Batista and Singh, 2021). Under these changing conditions, establishing stable, functional microbial communities has become more difficult, directly affecting plant productivity and the sustainability of agricultural systems (Martins et al., 2023).

Research on the plant microbiome has revealed the structural and functional diversity of microbial communities associated with the phyllosphere, rhizosphere, and endosphere. These communities influence plant nutrition, hormonal regulation, immune responses, and tolerance to abiotic stress (Ke et al., 2021). Microbiome

composition is determined by multiple factors, including host species, the soil environment, management practices, and environmental pressures (De Corato, 2020).

Despite these advances, limited information is available on the comparative efficiency of different capture systems for isolating native microorganisms under tropical conditions, particularly in Ecuadorian ecosystems. The interaction among trap type, substrate type, locality, and seasonality as determinants of microbial-colonization dynamics and the recovery of specific functional groups has likewise not been studied in depth. This knowledge gap limits the development of optimized methodological strategies for microbial bioprospecting in tropical agricultural systems.

Accordingly, this study evaluated seasonal dynamics and the efficiency of different capture systems for isolating functional native microorganisms from tropical soils in El Carmen canton, Ecuador. The hypothesis was that microbial-capture efficiency is influenced by the interaction among trap type, substrate type, locality, and seasonality.

Materials and methods

Normality and homoscedasticity were evaluated using the Shapiro-Wilk and Levene tests, respectively. The number of replicates was established in light of the exploratory nature of the study and the logistical conditions of field installation, which are characteristic of tropical systems. Logarithmic transformations were also applied to reduce intrinsic variability and ensure that the assumptions of the statistical analysis were met.

A factorial analysis of variance (ANOVA) was applied, considering the main effects and interactions among the four experimental factors. First-, second-, and third-order interactions were evaluated. Multiple comparisons among means were performed using Tukey's test ($\alpha = 0.05$).

All statistical analyses were conducted in RStudio (2024) using the stats, agricolae, car, and rstatix packages. This software ensured reproducibility, script traceability, and transparent validation of the results.

Field procedure

Selection and characterization of installation sites

Before the traps were installed, systematic exploratory sampling was conducted to identify representative microenvironments within each experimental property. Trees were selected according to predefined phytosanitary and soil criteria: (i) absence of visible symptoms of stress or disease, (ii) foliage cover greater than 70%, (iii)

homogeneous accumulation of surface litter, and (iv) soil structure with stable granular aggregation and no evidence of mechanical compaction (Quiñónez et al., 2018).

Each selected tree was georeferenced using a global positioning system (GPS) with submeter accuracy and coded according to the experimental treatment. Traps were installed along the outer perimeter of the crown projection (drip line), an area characterized by a high density of fine roots and greater rhizosphere activity, which favors plant-microorganism interaction and microbial colonization (Campo et al., 2014).

Preparation of the base substrate

Polished white rice was used as the carbon matrix because of its high content of readily hydrolyzable starch, which facilitated initial colonization by heterotrophic microbial communities (Alarcón et al., 2019). The rice was cooked in distilled water at an approximate 1:2 ratio (rice:water) for 10-15 minutes until it reached a semi-soft texture, ensuring structural uniformity without excessive gelatinization. It was then cooled to room temperature (25-28 °C) under hygienic conditions to prevent external contamination.

For the solid-substrate treatment, a nutrient solution composed of water, molasses, and fish meal was boiled for 10 minutes to reduce the exogenous microbial load and create a controlled selective environment. This mixture served as an additional source of carbon and organic nitrogen. Soy sauce was incorporated into the semiliquid substrate as a soluble nitrogen source, ensuring the immediate availability of amino acids and peptides for microbial proliferation. All substrates were prepared on the day of installation to avoid variation caused by prior fermentation.

Installation of traps in the field

Installation was conducted under natural environmental conditions using a standardized protocol to minimize experimental variability.

Site Preparation

A hole 15 ± 2 cm deep and approximately 20 cm in diameter was dug manually, taking care not to excessively disturb the surrounding soil structure (Orduz-Tovar et al., 2020).

Trap placement

The traps were positioned 10 cm below the soil surface, ensuring direct contact with the surrounding soil. They were then covered with the excavated soil and original litter to maintain microclimatic conditions similar to those occurring naturally, including moisture, temperature, and biological activity (Crespo et al., 2025).

Experimental coding

Each experimental unit was identified using numbered, weather-resistant stakes and a cartographic record to ensure spatial traceability.

Rainy-season management

To prevent water saturation and uncontrolled anoxic conditions, perimeter drainage ditches 5-8 cm deep were constructed around each installation point.

Exposure and colonization time

The exposure period was established according to microbial-colonization dynamics in tropical soils:

21 days for the solid-substrate protocol.

10-15 days for the semiliquid protocols.

These intervals balanced effective colonization against overfermentation or excessive substrate degradation.

No additional interventions were performed during the exposure period, and the natural conditions of the ecosystem were maintained (Crespo Ávila et al., 2025).

Extraction, preservation, and transport

The traps were removed manually while avoiding additional disturbance of the surrounding soil. They were immediately sealed in sterile airtight containers to prevent cross-contamination and exposure to atmospheric oxygen (Alarcón et al., 2019). Samples were placed in insulated containers with cold packs (4-8 °C) and transported to the laboratory within no more than 4 hours of extraction. Microbiological processing began on the day of collection to minimize changes in microbial viability.

Results and discussion

Combined effects of experimental factors on the abundance of native effective microorganisms

The four-factor analysis (trap type $\times$ substrate type $\times$ locality $\times$ season) revealed a significant interaction among factors ($P < 0.001$), indicating that microbial-capture efficiency did not depend on any experimental component in isolation, but rather on their combination under specific soil and environmental conditions.

Treatments classified in statistical category “a” produced the highest counts, expressed as colony-forming units per gram (CFU g⁻¹). The tub traps-Pupusá-liquid substrate combination yielded 6.65×10^6 CFU g⁻¹, followed by tub traps-Pupusá-solid substrate at 5.55×10^6 CFU g⁻¹. These results suggest that soil conditions at the Pupusá locality favored microbial colonization relatively independently of substrate type. This response may have been associated with higher organic-matter content, better structural



aggregation, or greater baseline biological activity (Table 1).

Table 1. Combined effect of trap type, locality, and substrate on the capture of native effective microorganisms in two climatic seasons.

Trap	Locality	Substrate	Rainy (CFU g ⁻¹)	Dry (CFU g ⁻¹)	Mean ($\bar{X}$)	Tukey ($\alpha=0.05$)
Tub traps	Pupusá	Solid	5.9×10^6	5.2×10^6	5.55×10^6	a
Cup traps	Pupusá	Liquid	2.2×10^6	2.4×10^6	2.30×10^6	a
Tub traps	Pupusá	Liquid	5.6×10^6	7.7×10^6	6.65×10^6	a
Cup traps	Pupusá	Solid	3.33×10^6	6.9×10^5	2.01×10^6	ab
Canister traps	ULEAM Farm	Liquid	3.2×10^6	6.8×10^6	5.0×10^6	ab
Canister traps	Pupusá	Solid	6.3×10^6	2.1×10^6	4.2×10^6	ab
Cup traps	ULEAM Farm	Liquid	9.9×10^6	6.5×10^6	8.2×10^6	ab
Canister traps	Pupusá	Liquid	1.7×10^6	1.4×10^6	1.55×10^6	abcde
Tub traps	ULEAM Farm	Liquid	4.4×10^6	4.0×10^6	4.2×10^6	bcd
Tub traps	ULEAM Farm	Solid	8.7×10^5	8.2×10^4	4.76×10^5	cde
Cup traps	ULEAM Farm	Solid	5.2×10^6	5.3×10^6	5.25×10^6	de
Canister traps	ULEAM Farm	Solid	5.5×10^6	1.9×10^6	2.85×10^6	e

The cup traps-ULEAM Farm-liquid substrate treatment produced the numerically highest value in the experiment, 8.20×10^6 CFU g⁻¹; however, its placement in statistical group “ab” indicated that experimental variability limited its differentiation from other high-performing treatments.

In contrast, the tub traps-ULEAM Farm-solid substrate combination had the lowest capture efficiency, 4.76×10^5 CFU g⁻¹, and was grouped in lower statistical categories. This reduction may have been related to lower effective water availability or differences in local microbial dynamics during the dry season (Table 1).

From a seasonal perspective, the rainy season had a higher overall mean (2.31×10^6 CFU g⁻¹) than the dry season (1.69×10^6 CFU g⁻¹), confirming that moisture availability was a determining factor in the activity, proliferation, and mobility of native microorganisms in tropical soils from El Carmen (Table 1).

The greater capture of microorganisms during the rainy season confirmed the determining role of soil moisture in microbial metabolic activation and mobility in tropical ecosystems (Crespo et al., 2025). Water availability increased soil-pore connectivity and facilitated the diffusion of soluble substrates, favoring colonization and heterotrophic growth. Recent studies have shown that climatic seasonality significantly alters the structure and abundance of the soil microbiome, particularly in tropical systems with pronounced dry-rainy alternation (Schmidt et al., 2019).

The reduction observed in the dry season may be attributed to water-stress-induced microbial dormancy, a phenomenon extensively documented in tropical soils where water availability regulates respiration and nutrient mineralization (Ray et al., 2020).

Counts of cellulolytic microorganisms

The capture dynamics of cellulolytic microorganisms varied markedly among the experimental combinations. The maximum value, 7.3×10^3 colony-forming units per gram (CFU g⁻¹; Table 2), occurred in the cup system during the rainy season at ULEAM Farm with liquid substrate. Nevertheless, multiple-comparison analysis showed broad overlap among treatments, with no clearly differentiated statistical groups for most combinations ($P>0.05$).

Overall, the liquid substrate produced a higher mean capture than the solid substrate, suggesting that greater availability of soluble compounds promoted the metabolic activity of cellulolytic microorganisms. However, several experimental combinations produced low values or no detectable growth (0 CFU g⁻¹), indicating that the presence of this functional group was limited and conditioned by specific microenvironmental factors associated with seasonality and the interaction between capture system and substrate.

The greater capture of native effective microorganisms during the rainy season demonstrates the strong dependence of the soil microbiome on water availability in tropical ecosystems. Soil moisture regulates microbial metabolic activity by increasing pore-space connectivity and the diffusion of soluble substrates, which favors colonization of experimental carbon matrices. Aguilar-Paredes et al. (2023) showed that moisture pulses activate dormant microbial processes and alter soil-community dynamics through changes in respiration and mineralization. In

tropical environments with pronounced seasonality, Sokol et al. (2022) reported significant seasonal variation in bacterial-community structure and abundance, associated primarily with moisture content and carbon availability.

Table 2. Capture of cellulolytic microorganisms by trap type, season, locality, and substrate.

Trap type	Season	Locality	Solid (CFU g ⁻¹)	Liquid (CFU g ⁻¹)	Mean ($\bar{X}$)	Tukey ($\alpha=0.05$)
Cup traps	Dry	Pupusá	1.7×10^3	2.0×10^3	1.85×10^3	a
Cup traps	Dry	ULEAM Farm	1.7×10^3	5.0×10^2	1.10×10^3	ab
Canister traps	Dry	Pupusá	0	3.3×10^3	1.65×10^3	ab
Canister traps	Rainy	Pupusá	5.0×10^2	0	2.5×10^2	abc
Cup traps	Rainy	ULEAM Farm	0	1.7×10^3	8.5×10^2	abc
Cup traps	Rainy	ULEAM Farm	0	7.3×10^3	3.65×10^3	abcd
Tub traps	Rainy	ULEAM Farm	0	0	0	bcd
Canister traps	Rainy	ULEAM Farm	0	0	0	bcd
Tub traps	Dry	ULEAM Farm	0	0	0	e
Tub traps	Dry	Pupusá	0	0	0	e
Tub traps	Rainy	Pupusá	0	0	0	e
Canister traps	Dry	ULEAM Farm	0	0	0	e

The better performance of liquid-substrate treatments suggests that the immediate availability of readily metabolizable compounds promoted heterotrophic microorganism growth. The incorporation of soluble carbon and nitrogen sources has been identified as a determining factor in the functional organization of the soil microbiome (Trivedi et al., 2021). The greater capture observed in certain combinations may therefore be interpreted as a functional response to substrate quality rather than to the physical type of trap.

Counts of captured actinomycetes

Actinomycete capture during the dry season showed a markedly heterogeneous distribution among the evaluated experimental combinations. The highest values occurred in the tub-type trap with both solid substrate (3.0×10^8 CFU g⁻¹) and liquid substrate (2.39×10^8 CFU g⁻¹), forming the highest statistical group ($P < 0.05$; Table 3). In contrast, canister traps produced the lowest counts in both substrates (2.75×10^7 and 3.0×10^7 CFU g⁻¹), while cup traps yielded intermediate values, with a more pronounced decrease in liquid substrate (6.75×10^7 CFU g⁻¹).

Table 3. Effect of trap type and substrate type on captured actinomycete counts (CFU g⁻¹) during the dry season in tropical soil from El Carmen, Ecuador.

Trap type	Solid (CFU g ⁻¹)	Liquid (CFU g ⁻¹)
Tub trap	3.0×10^8 a	2.39×10^8 a
Cup traps	2.55×10^8 b	6.75×10^7 b
Canister traps	2.75×10^7 c	3.0×10^7 c

This behavior was consistent with Maestre et al. (2015), who showed that microenvironmental structure directly influences the distribution and activity of soil microbial communities, especially in tropical ecosystems where water variability modulates biogeochemical processes. In this context, the greater efficiency of the tub-type system may be explained by its greater thermal stability and moisture-retention capacity, factors recognized as determinants of soil-actinobacteria proliferation (Placella, Brodie, and Firestone, 2012).

The absence of consistent statistical differences between solid and liquid substrate within the most efficient system indicates that the capture matrix was not the principal limiting factor. Instead, the generation of a favorable microenvironment maximized colonization. Various studies have noted that actinomycetes display high physiological plasticity and can develop in different matrices whenever usable carbon and adequate aeration are available (Maestre et al., 2015).

Counts of solubilizing microorganisms

With solid substrate, cup traps ($4.81 \log_{10}$ CFU g⁻¹) and canister traps ($5.63 \log_{10}$ CFU g⁻¹) produced the highest values, whereas the tub trap yielded a lower value ($4.89 \log_{10}$ CFU g⁻¹). This pattern indicated that, with a solid matrix, capture efficiency was higher in systems with greater internal volume or effective contact area (Table 4).

Table 4. Trap type $\times$ substrate type interaction for phosphate-solubilizing microorganisms ($\log_{10}$ CFU g⁻¹).

Substrate type	Tub trap ($\log_{10}$ CFU g ⁻¹)	Cup traps ($\log_{10}$ CFU g ⁻¹)	Canister traps ($\log_{10}$ CFU g ⁻¹)
Solid	4.89 b	4.81 a	5.63 a
Liquid	5.63 a	1.35 b	3.13 b

In contrast, with liquid substrate, the tub trap reached the highest value ($5.63 \log_{10}$ CFU g⁻¹), exceeding cup traps ($1.35 \log_{10}$ CFU g⁻¹) and canister traps ($3.13 \log_{10}$ CFU g⁻¹). This response showed that system efficiency depended on substrate type, which altered the relative performance of the capture systems during the dry season in tropical soils.

In tropical ecosystems, phosphorus availability is frequently limited by fixation in iron and aluminum complexes, restricting the fraction that is bioavailable to solubilizing

microorganisms (Maestre et al., 2015). In this context, the limited statistical differentiation among treatments could be explained by functional homogenization of microbial communities under water stress, a phenomenon described in tropical-soil studies in which drought reduces enzymatic activity associated with phosphorus solubilization (Trivedi et al., 2021).

The differential response among capture systems may be associated with variation in their internal microenvironments, particularly in oxygenation and thermal stability, which are key factors in soil-microbial-community dynamics (Table 5).

Table 5. Trap type $\times$ substrate type interaction for captured nitrogen-fixing microorganisms (CFU g⁻¹) during the rainy season.

Trap type	Solid (CFU g ⁻¹)	Liquid (CFU g ⁻¹)
Tub trap	9.0×10^2 a	5.5×10^2 b
Cup traps	2.25×10^2 c	3.0×10^2 b
Canister traps	5.5×10^2 b	2.57×10^3 a

The greater recovery in the canister-liquid substrate treatment suggests that, under high ambient humidity, the liquid matrix promoted the metabolic activation and proliferation of phosphate-solubilizing microorganisms. This response is consistent with studies indicating that water availability increases soil biological activity and nutrient availability by enhancing the diffusion of soluble compounds and microbial mobility (Trivedi et al., 2021).

The differential response among capture systems may be associated with variation in internal microenvironments, particularly oxygenation and thermal stability. Phosphate-solubilizing microorganisms may be affected by oxygen conditions and substrate availability, factors that influence their metabolic activity and solubilization capacity (Trivedi et al., 2021).

Conclusion

Microbial-capture efficiency was significantly determined by the interaction among trap type, substrate type, and seasonality. System architecture and water availability conditioned the isolation of functional microorganisms from tropical soil, with greater yields in specific combinations and during the rainy season.

Seasonality was a determining factor in microbial dynamics: the overall mean capture was higher during the

rainy season (2.31×10^6 CFU g⁻¹) than during the dry season (1.69×10^6 CFU g⁻¹), confirming the critical influence of water availability on the activity and proliferation of native soil microorganisms.

Conflict of interest

The authors declare that they had no conflicts of interest at any stage of this publication.

References

- Adeleke, B. S. and Babalola, O. O. (2021). The endosphere microbial communities, a great promise in agriculture. *International Microbiology*, 24(1), 1-17. <https://doi.org/10.1007/s10123-020-00140-2>
- Aguilar-Paredes, A., Valdés, G., Araneda, N., Valdebenito, E., Hansen, F. and Nuti, M. (2023). Microbial community in the composting process and its positive impact on the soil biota in sustainable agriculture. *Agronomy*, 13(2), 542. <https://doi.org/10.3390/agronomy13020542>
- Alarcón Camacho, J., Recharte Pineda, D. C., Yanqui Díaz, F., Moreno Llacza, S. M., Montes Yarasca, I. M., Buendía Molina, M. A. (2019). Elaboración de un biofertilizante a partir de microorganismos eficientes autóctonos en Perú. *Anales Científicos*, 80(2), 515-522. DOI: <http://dx.doi.org/10.21704/ac.v80i2.1484>
- Alarcón, J., Recharte, D. C., Yanqui, F., Moreno, S. M., Buendía, M. A. (2020). Fertilizar con microorganismos eficientes autóctonos tiene efecto positivo en la fenología, biomasa y producción de tomate (*Lycopersicon esculentum* Mill). *Scientia Agropecuaria*, 11(1), 67-73. DOI: 10.17268/sci.agropecu.2020.01.08
- Batista, B. D. and Singh, B. K. (2021). Realities and hopes in the application of microbial tools in agriculture. *Microbial Biotechnology*, 14(4), 1258-1268. <https://doi.org/10.1111/1751-7915.13866>
- Campo Martínez, A. del P., Acosta Sánchez, R. L., Morales Velasco, S. y Prado, F. A. (2014). Evaluación de microorganismos de montaña (mm) en la producción de acelga en la meseta de Popayán. *Biotecnología en el Sector Agropecuario y Agroindustrial*, 12(1), 79-87. <https://revistas.unicauca.edu.co/index.php/biotecnologia/article/view/322>

- Crespo Ávila, J. A., Suquilanda Valdivieso, M. B., Carranza Cárdenas, C. C., Arellano Ibarra, K. V. y Vera Benites, L. F. (2025). Caracterización morfológica y optimización de bio-insumo a base de microorganismos eficientes. *Universidad, Ciencia y Tecnología*, 29(126), 89-99. <https://doi.org/10.47460/uct.v29i126.925>
- De Corato, U. (2020). Soil microbiota manipulation and its role in suppressing soil-borne plant pathogens in organic farming systems under the light of microbiome-assisted strategies. *Chemical and Biological Technologies in Agriculture*, 7(1), 17. <https://doi.org/10.1186/s40538-020-00183-7>
- De Souza, R. S. C., Armanhi, J. S. L. and Arruda, P. (2020). From microbiome to traits: designing synthetic microbial communities for improved crop resiliency. *Frontiers in Plant Science*, 11, 1179. <https://doi.org/10.3389/fpls.2020.01179>
- Iquebal, M. A., Jagannadham, J., Jaiswal, S., Prabha, R., Rai, A. and Kumar, D. (2022). Potential use of microbial community genomes in various dimensions of agriculture productivity and Its management: A review. *Front. Microbiol.* 13:708335. doi:10.3389/fmicb.2022.708335
- Ke, J., Wang, B. and Yoshikuni, Y. (2021). Microbiome engineering: synthetic biology of plant-associated microbiomes in sustainable agriculture. *Trends in Biotechnology*, 39(3), 244-261.
- Khmelevtsova, L. E., Sazykin, I. S., Azhogina, T. N. and Sazykina, M. A. (2022). Influence of agricultural practices on bacterial community of cultivated soils. *Agriculture*, 12(3), 371. <https://doi.org/10.3390/agriculture12030371>
- Maestre, F. T., Delgado-Baquerizo, M., Jeffries, T. C., Eldridge, D. J., Ochoa, V., Gozalo, B., Quero, J. L., García-Gómez, M., Gallardo, A., Ulrich, W., Bowker, M. A., Arredondo, T., Barraza-Zepeda, C., Bran, D., Florentino, A., Gaitán, J., Gutiérrez, J. R., Huber-Sannwald, E., Jankju, M., Mau, R. L., Miriti, M., Naseri, K., Ospina, A., Stavi, I., Wang, D., Woods, N. N., Yuan, X., Zaady, E. and Singh, B. K. (2015). Increasing aridity reduces soil microbial diversity and abundance in global drylands. *Proc. Natl. Acad. Sci.*, 112(51), 15684-15689. <https://doi.org/10.1073/pnas.1516684112>
- Martins, S. J., Pasche, J., Silva, H. A. O., Selten, G., Savastano, N., Abreu, L. M., Bais, H. P., Garrett, K. A., Kraistudomsook, N., Pieterse, C. M. J. and Cernava, T. (2023). The use of synthetic microbial communities to improve plant health. *Phytopathology*, 113(8), 1369-1379. <https://doi.org/10.1094/PHYTO-01-23-0016-IA>
- Ordúz-Tovar, S. A., Machado-Cuellar, L., Rojas-Basto, L. C. y Amaya-Ucue, E. D. (2020). Dinámica biogeoquímica por microorganismos edáficos en sistemas agroforestales de cacao: Revisión de literatura científica. *Revista Sennova: Revista del Sistema de Ciencia, Tecnología e Innovación*, 5(1), 53-72. <https://doi.org/10.23850/23899573.2496>
- Placella, S. A., Brodie, E. L. and Firestone, M. K. (2012). Rainfall-induced carbon dioxide pulses result from sequential resuscitation of phylogenetically clustered microbial groups. *Proceedings of the National Academy of Sciences*, 109(27), 10931-10936. <https://doi.org/10.1073/pnas.1204306109>
- Quiñónez Martínez, M., Enríquez Anchondo, I. D., Flores Margez, J. P., Palacios Ramírez, K. Y., Olivas Sánchez, M. P., Garza Ocañas, F., Lebgue Keleng, T. y Nájera Medellín, J. A. (2018). Comunidades vegetales en suelo de ecosistema semiárido y su relación con hongos micorrízicos. *Terra Latinoamericana*, 36, 381-391. DOI: <https://doi.org/10.28940/terra.v36i4.401>
- Ray, P., Lakshmanan, V., Labbé, J. L. and Craven, K. D. (2020) Microbe to microbiome: A paradigm shift in the application of microorganisms for sustainable agriculture. *Front. Microbiol.* 11, 622926. doi: 10.3389/fmicb.2020.622926
- Saad, M. M., Eida, A. A. and Hirt, H. (2020). Tailoring plant-associated microbial inoculants in agriculture: a roadmap for successful application. *Journal of Experimental Botany*, (13), 3878-3901. <https://doi.org/10.1093/jxb/eraa11171>
- Schmidt, J. E., Kent, A. D., Brisson, V. L. and Gaudin, A. C. M. (2019). Agricultural management and plant selection interactively affect rhizosphere microbial community structure and nitrogen cycling. *Microbiome*, 7, 146. <https://doi.org/10.1186/s40168-019-0756-9>
- Sokol, N. W., Slessarev, E., Marschmann, G. L., Nicolas, A., Blazewicz, S. J., Brodie, E. L., Firestone, M. K., Foley, M. M., Hestrin, R., Hungate, B. A., Koch, B. J., Stone, B. W., Sullivan, M. B., Zablocki, O., LLNL Soil Microbiome Consortium, and Pett-Ridge, J. (2022). Life and death in the soil microbiome: how ecological processes influence biogeochemistry. *Nature*



Reviews. Microbiology, 20(7), 415-430. <https://doi.org/10.1038/s41579-022-00695-z>

Trivedi, P., Mattupalli, C., Eversole, K. and Leach, J.E. (2021), Enabling sustainable agriculture through understanding and enhancement of microbiomes. *New Phytol*, 230: 2129-2147. <https://doi.org/10.1111/nph.17319>

Statement on the use of artificial intelligence

During preparation of this work, the authors used artificial-intelligence tools to support methodological guidance in the use of R software and to improve the manuscript's grammar and spelling. The statistical analysis, interpretation of results, and final scientific writing were carried out entirely by the authors. After using these tools, the authors carefully reviewed and edited the content and assume full responsibility for the publication.

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Leonardo Avellán-Vásquez: Methodology, Investigation, Formal analysis, Writing - original draft, and Writing - review & editing. **Cesar Cruz-Rey:** Investigation, Methodology, and Resources. **María Chango-Quishpe:** Investigation, Methodology, and Resources. **Tamara Pinargote-Muñoz:** Writing and Writing - review & editing.