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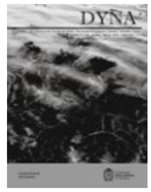

UNIVERSIDAD NACIONAL DE COLOMBIA

Evaluation of nitrogen-fixing and phosphorus-solubiling microorganisms in Astromelian (*Alstroemeria aurantiaca*), cultivation

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Abstract
The Ecuadorian floriculture sector is currently facing challenges due to the decline in soil nutritional content and productivity. This situation, coupled with nitrogen (N) losses and poor soil phosphorus (P) assimilation, has led to reduced yields in ornamental species such as lily of the Incas (*Alstroemeria aurantiaca*), resulting in significant economic losses. Various alternatives were evaluated to address these issues. A Randomized Complete Block Design (RCBD) was employed using a two-factor scheme, including the A×B interaction and the intercept. The experimental conditions consisted of microbial applications at doses of 1, 2, and 3 L/ha, applied directly to the soil as a supplementary nutrient treatment. Treatment T2 (2 L/ha), which comprised a microbial consortium, exhibited the best performance. Total production costs were estimated at 3,440 USD per hectare, with an economic efficiency of 2,560 USD, which was rated as satisfactory.

Keywords: beneficial soil microbiota; absorption; phosphate-solubilizing microorganisms; nitrifying bacteria; ornamentals.

Evaluación de microorganismos fijadores de nitrógeno y solubilizadores de fósforo en el cultivo de Astromelias (*Alstroemeria aurantiaca*)

Resumen
El sector florícola ecuatoriano atraviesa dificultades debido a la disminución del contenido nutricional y productividad del suelo, esto unido a pérdidas de N y poca asimilación de P del suelo hace que disminuyan los rendimientos de especies ornamentales como astromelia (Alstroemeria aurantiaca) que provocan grandes pérdidas económicas. Se evaluaron alternativas para solucionar estas problemáticas. Se empleó un DBCA con esquema de dos factores que incluye la interacción A×B y el intercepto. Las condiciones experimentales fueron: 1, 2, 3 L/ha, de microorganismos, aplicados en directamente al suelo por aplicación suplementaria de nutrientes. El tratamiento T2 (2 L/ha), fue el que mejor se comportó, el mismo comprende una mezcla de microorganismos. Los gastos completos de producción se estimaron en 3 440 USD por hectárea. Y una eficiencia económica de 2 560 USD, estimado de satisfactoria.

Palabras clave: microbiota benéfica del suelo; absorción; fosfosolubilizadores; nitrificantes; ornamentales.

1 Introduction

Ecuador produces and exports a wide variety of ornamental species, among which rose (Rosa sp.), carnation (Dianthus caryophyllus), and alstroemeria (Alstroemeria aurantiaca) stand out [6]. The latter, belonging to the family Amaryllidaceae, occupies 0.5% of the floricultural area in Ecuador and is increasingly becoming a crop of great interest for export. It enjoys high demand in both national and international markets—particularly in countries such as Canada, Japan, the United States (accounting for 80% of exports), the Russian Federation, and the European Community—due to its vibrant colors and elegant appearance [1,2].

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For flower growers in the Orongoloma community, located in the Cayambe canton, Pichincha province, significant nitrogen (N) losses occur after soil applications, mainly due to leaching and volatilization. This necessitates both more frequent applications and increased dosages, thereby raising production costs.

Additionally, challenges have been reported regarding the assimilation and bioavailability of phosphorus (P) by plants, which also leads to increased application costs [4,5].

The International Plant Nutrition Institute [9] emphasized that biological nitrogen fixation is gaining growing interest due to the ongoing oil crisis, as petroleum is a major energy source and raw material for ammonia (NH_3) production [8,10]. Moreover, ecological implications associated with the intensive use of nitrogen fertilizers cannot be overlooked. Phosphorus, along with nitrogen, is essential for boosting crop productivity and achieving high yields. However, despite its presence in both organic and inorganic forms in the soil, its absorption by plant roots is limited due to rapid fixation in the soil, making it difficult for plants to extract [22,23].

The use of beneficial microorganisms naturally present in the soil, as well as those applied artificially—such as nitrogen-fixing and phosphorus-solubilizing strains—represents a promising and increasingly adopted strategy worldwide. This approach provides economic, productive, and environmental benefits [1].

In this research to evaluate the application of nitrogen-fixing and phosphorus-solubilizing microorganisms in Alstroemeria aurantiaca cultivation in the Cayambe canton, Pichincha province, in order to improve crop quality and yield.

To determine the amount of nitrogen fixed in the soil through the application of nitrogen-fixing microorganisms in alstroemeria cultivation.

To determine the extent of phosphorus solubilization in the soil through the application of phosphorus-solubilizing microorganisms in alstroemeria cultivation

To establish a methodology for improving productivity and yield in alstroemeria cultivation using efficient microorganisms.

To conduct an economic evaluation of the application of nitrogen-fixing and phosphorus-solubilizing microorganisms.

2 Materials and methods

2.1 Location and Description of the experimental area

This research was conducted at the "MILFLORES" farm, located in the Orongoloma community of Cayambe canton, Pichincha province, Ecuador. The geographical coordinates are: 0°02′16″ N latitude, 78°07′02″ W longitude, and an altitude of 3,000 meters above sea level. The area has an average annual temperature of 15 °C, annual precipitation of 1,200 mm, relative humidity of 65%, wind speed of 10 m/s, and total annual sunshine duration of approximately 2,000 hours.

2.2 Plant material

The study involved 1,200 alstroemeria plants obtained through hybridization and propagation of the ‘Esmeraldas’ group, grown in a crop established one year prior to the experiment.

2.3 Studied variables

2.3.1 Variable A:

Nitrogen-fixing microorganisms (Azospirillum, Azotobacter spp., and Rhizobium) and phosphorus-solubilizing microorganisms (Pseudomonas fluorescens).

2.3.2 Variable B:

Dose 1: 1 L/ha; Dose 2: 2 L/ha; Dose 3: 3 L/ha

2.4 Treatments

2.4.1 Experimental design

A Completely Randomized Block Design (CRBD) was used, consisting of four treatments in a factorial arrangement (A × B) + 1, with three replications per treatment (Table 1).

Statistical differences among treatments were determined using Tukey’s test at a 5 % significance level.

Data were processed using the INFOSTAT statistical software.

2.4.2 Experimental unit characteristics

Area per experimental unit: 24 m²
Total experimental area: 288 m² (24 m² × 12)
Total trial area: 600 m²
Planting density: 0.30 m × 0.80 m (20,000 plants/ha)
Number of plants per m²: 2
Number of plants per experimental unit: 100
Total number of experimental units: 12

2.4.3 Analysis of variance (ANOVA)

The variables were analyzed using a one-way Analysis of Variance (ANOVA), according to the following scheme (Table 2).

Table 1.
Treatments applied in the study

Treatment	Organic Amendments (cc/experimental unit)	Dose (L/ha)	Description
1	5	1	Beneficial Microorganisms
2	10	2	Beneficial Microorganisms
3	15	3	Beneficial Microorganisms
4	0	0	Control (Untreated)

Source: own elaboration

Table 2.
ANOVA Scheme

Source of Variation	Degrees of Freedom (DF)
Total	11
Replications	2
Treatments	3
Microorganisms (Factor A)	0
Dose (Factor B)	2
Interaction (A × B)	0
Control vs. Others	1
Experimental Error	6
Coefficient of Variation	(%)

Source: own elaboration

2.4.4 Trial Management

The trial area was set up with a total surface of 600 m², including twelve 30-meter beds (replications), which constituted the experimental units and corresponded to the different treatments. The Alstroemeria crop had been established on 30 beds and had been in production for approximately five years at the time of the study.

2.4.5 Application of microorganisms in the experimental units

A ¾-inch VENTURI injector, delivering 2 L/min, was used for the liquid application of microorganisms via drench (soil drenching) according to the proposed

The solution was applied directly to the center of each bed, as close as possible to the plant roots to maximize uptake.

A total of 4 L of microbial solution was applied per experimental unit. Applications were made weekly for 13 weeks, following the same procedure for all treatments and replications.

2.4.6 Fertilization

Fertilization was carried out according to the crop's standard schedule: 2 kg of compound fertilizer 15-15-15.

The highest number of shoots (N-P-K) were applied monthly per 30-meter bed. The solid amendment was manually applied and incorporated into the soil with a manual aerator.

2.4.7 Irrigation

Irrigation was performed using a shower head attached to a ¾-inch hose to dissolve and distribute the incorporated fertilizer. Irrigation was applied every other day during cloudy or rainy conditions, and daily during dry periods.

2.4.8 Pest and disease control

Phytosanitary control was not required during the study period, as no pests or diseases were observed that could directly affect production.

2.4.9 Harvest

Harvesting was done manually by collecting flower stems ready for cutting. The stems were grouped into bunches of ten, placed in protective sleeves, and packaged for sale in local florists and for export.

2.4.10 Evaluated variables

Number of shoots per m²

Quantity of nitrogen fixed after microorganism application

Amount of phosphorus available to the plant at the end of the study

Harvested stem length doses

2.4.11 Economic analysis

An economic evaluation was conducted to assess the cost-effectiveness of using nitrogen-fixing and phosphorus-solubilizing microorganisms under the different treatment conditions.

3 Results and discussion

3.1 Number of Shoots/m²

In the ANOVA (Table 3), significant differences were observed for the control in relation to the other treatments, as well as between treatments and doses. However, there was no significant interaction between microorganisms × Dose was presented by Treatment 2 (T2), where efficient microorganisms were applied at a dose of 2 L/ha, resulting in 10 shoots/m². The Coefficient of Variation (CV) was 8.8 %, with an average of 8 shoots/m².

The laboratory analysis results for Treatment 1 (T1) (Table 4) show that 433.52 ppm of N were fixed, retaining 137.52 ppm of N, compared to the initial laboratory analysis which reported 296 ppm of N in the soil.

As can be observed, the N values after the application of microorganisms are at adequate levels for normal growth.

These same analyses show an Electrical Conductivity (EC) of 3.98 dS/m, which indicates an accumulation of nutrients. According to [12] and [17], this value could be due to an insufficient quantity of microorganisms in the soil to benefit the availability of present nutrients. According to [13], this crop tolerates maximum ranges of up to 3 dS/m (Table 5).

Table 3.
Average number of astromelia shoots/m²

Treatments			
No.	**Microorganisms**	**Dose (L/ha)**	**Number of Shoots**
2.	Microorganisms	10 a	2
3.	Microorganisms	9 ab	3
1.	Microorganisms	7 bc	1
4.	Absolute control	6 c	0
C.V. (%) = 8.8			

Means with the same letter are not statistically different according to Tukey's test at 5% significance
Source: own elaboration

Table 4.
Amount of N fixed after microorganism applications

Soil Analysis											
SYMBOL	***pH***	***EC***	***MOS***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,32	2,31	4,52	296,00	158,4	3,07	27,12	3,48	0,76	6,32	
INDICATORS	B	A	OK		A	A	OK	A	OK	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIDAD	ppm	ppm	Ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULTADO	159,7	14,23	39,4	1,42	69,14	11,22	7,8	1,13	30,71	34,42
INDICADOR	A	A	A	OK	OK	A	A	B	A	OK

Texture		
SAND	LIMO	CLAY
60	30	8
LOAMY SAND		

A: high;
B: low;
OK: adecuate
m/g: miligrams per liter;
meq/100g: miliequivalents per hundred grams
uds: units;
%: porcentaje

Source: own elaboration

Table 5.
Results of the soil sample sent to the laboratory before the start of the investigation

Soil Analysis											
SYMBOL	***pH***	***EC***	***MOS***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,64	3,98	2,46	3,5	430,02	73,82	5,37	21,5	4,23	1,22	13,07
INDICATOR	OK	A	B	B	A	A	A	A	OK	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	159,7	12,95	9,42	1,47	43,54	15,11	5,09	0,79	16,92	32,32
INDICATOR	A	OK	OK	OK	OK	A	A	B	A	OK

Texture		
SAND	LIMO	CLAY
60	32	8
LOAMY SAND		

A: high;
B: low;
OK: adecuate
m/g: miligrams per liter;
meq/100g: miliequivalents per hundred grams
uds: units;
%: porcentaje

Source: own elaboration

Table 6.
Results of the soil analyses performed in the experiment

Soil Analysis											
SYMBOL	***pH***	ˀ	***MO***	***H4***	***NO3***						
UNIT	s	/m	%	›m	ppm	›m	100g	ι/100g	'100g	100g	m
RESULT	,36	7	2,59	9	332,58	7,72					,33
INDICATOR					A	OK					

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	205,5	9,85	7,07	0,9	41,1	36	8,07	0,67	13,02	26,28
INDICATOR	A	OK	OK	B	OK		A	B	OK	OK

Texture		
SAND	LIMO	CLAY
60	34	6
LOAMY SAND		

A: high;
B: low;
OK: adecuate
m/g: miligrams per liter;
meq/100g: miliequivalents per hundred grams
uds: units;
%: porcentaje

Source: own elaboration

In the results for T2 (Table 6), it is observed that 332.58 ppm of N were fixed, retaining 2,9 ppm of N in the soil. Also, the EC is 2.87, which indicates a sufficient quantity of nutrients for plant consumption and is within the crop's tolerance range for better yield. [19] and [13,20] obtained the best results using medium doses of microorganisms, as low doses risk not all nutrients being solubilized for proper plant assimilation. High doses, however, solubilize very quickly and effectively, and the high quantity of microorganisms leads to rapid competition, but without more elements to work on, they die, which does not allow for adequate function and increases costs.

Regarding the results for T3 (Table 7), 454.35 ppm of N were fixed, a difference of 158.35 ppm of N compared to the initial investigation results. The laboratory analysis for this treatment showed an EC value of 3.66, which, like Treatment 1, is above the crop's tolerance range.

Table 7.
Results of soil analyses performed in treatment three

Soil Analysis											
SYMBOL	***pH***	***EC***	***MOS***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,26	3,66	2,43	5,65	448,7	61,77	3,07	20,06	3,84	0,81	15,35
INDICATOR	B	A	B	B	A	A	A	OK	OK	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	185,8	9,81	11,78	1,61	97,44	18,96	5,23	1,25	25,09	27,78
INDICATOR	A	OK	OK	OK	A	A	A	B	A	OK

Texture		
SAND	LIMO	CLAY
60	32	8
LOAMY SAND		

A: high;
B: low;
OK: adecuate
m/g: miligrams per liter;
meq/100g: miliequivalents per hundred grams
uds: units;
%: porcentaje

Source: own elaboration

Table 8.
Results of soil sample treatment 4. End of the investigation

Soil Analysis											
SYMBOL	***pH***	***EC***	***MO***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,3	0,55	2,16	1,05	0,79	44,33	3,07	12,81	0,47	0,55	13,02
INDICATOR	B	OK	B	B	B	OK	A	OK	B	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	416,2	6,77	3,1	0,12	18,9	61,48	27,09	0,15	1,97	16,9
INDICATOR	A	OK	OK	B	OK	A	A	B	B	OK

Texture		
SAND	LIMO	CLAY
64	28	8
LOAMY SAND		

A: high;
B: low;
OK: adecuate
m/g: miligrams per liter;
meq/100g: miliequivalents per hundred grams
uds: units;
%: porcentaje

Source: own elaboration

Table 9.
Results of soil sample treatment 1, P fixation

Soil Analysis											
SYMBOL	***pH***	***EC***	***MO***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,64	3,98	2,46	3,5	430,02	73,82	5,37	21,5	4,23	1,22	13,07
INDICATOR	OK	A	B	B	A	A	A	A	OK	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	159,7	12,95	9,42	1,47	43,54	15,11	5,09	0,79	16,92	32,32
INDICATOR	A	OK	OK	OK	OK	A	A	B	A	OK

Texture		
ARENA	LIMO	CLAY
60	32	8
LOAMY SAND		

A: high;
B: low;
OK: adecuate
m/g: miligrams per liter;
meq/100g: miliequivalents per hundred grams
uds: units;
%: porcentaje

Source: own elaboration

The results for the control, Treatment 4 (T4), shown in Table 8, indicate that 1.84 ppm of N were fixed in the soil. This data corroborates the problem identified at the beginning of the investigation. It suggests that alstroemeria growers do not achieve adequate N levels in the soil before the next fertilizer application (every 20 days), requiring additional N inputs, which increases production costs. In Ecuador, some floriculturists initially apply 296 ppm of N with fertilizer, but this element is lost over time, reaching 1.84 ppm of N by the next application.

According to [14] and [15,18], the EC in this treatment was 0.55 dS/m, and the results verify that microorganisms are fundamental for agriculture as they make elements retained in the soil available for better plant utilization.

Amount of P available for the plant at the end of the investigation

Similar to N fixation, P content in the soil was assessed based on laboratory results, summarized below.

According to initial results, 73,82 ppm of P were fixed in the soil. In the T1 results (Table 9), 73.82 ppm of P were obtained, a difference of 47,72 compared to the initial analysis (Table 10), indicating that this amount could have been solubilized by microorganism activity.

Similarly, T2 (Table 11) reports 61,77 ppm of P, indicating that 109.49 ppm of P were solubilized for plant uptake, compared to the initial analysis.

Furthermore, the results for T3 (Table 12) show P values of 44,33 ppm, indicating that 106,1 ppm of this element were solubilized.

Table 10.
Results of soil sample treatment 1, for P fixation

Soil Analysis											
SYMBOL	***pH***	***EC***	***MO***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,36	2,87	2,59	2,9	332,58	47,72	3,58	19,4	2,4	0,9	13,33
INDICATOR	B	A	B	B	A	OK	A	OK	OK	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	205,5	9,85	7,07	0,9	41,1	20,86	8,07	0,67	13,02	26,28
INDICATOR	A	OK	OK	B	OK	A	A	B	OK	OK

Texture				
ARENA	LIMO	CLAY	**A:** high;	
60	34	6	**B:** low;	**meq/100g:** miliequivalents per hundred grams
LOAMY SAND			**OK:** adecuate	**uds:** units;
			m/g: miligrams per liter;	**%:** porcentaje

Source: own elaboration

Table 11.
Results of soil sample treatment 3 for P fixation

Soil Analysis											
SYMBOL	***pH***	***EC***	***MO***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	ppm
RESULT	6,26	3,66	2,43	5,65	448,7	61,77	3,07	20,06	3,84	0,81	15,35
INDICATOR	B	A	B	B	A	A	A	OK	OK	B	A

SYIMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIDAD	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULTADO	185,8	9,81	11,78	1,61	97,44	18,96	5,23	1,25	25,09	27,78
INDICADOR	A	OK	OK	OK	A	A	A	B	A	OK

Textura				
			A: high;	
SAND	LIMO	ARCILLA	**B:** low;	**meq/100g:** miliequivalents per hundred grams
60	32	8	**OK:** adecuate	**uds:** units;
FRANCO ARENOSO			**m/g:** miligrams per liter;	**%:** porcentaje

Source: own elaboration

Table 12.
Resultados del tratamiento 3 para fijación de P

Soil Analysis											
SYMBOL	***PH***	***EC***	***MO***	***NH4***	***NO3***	***P***	***K***	***Ca***	***Mg***	***Na***	***Cu***
UNIT	uds	dS/m	%	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g	Ppm
RESULT	6,3	0,55	2,16	1,05	0,79	44,33	3,07	12,81	0,47	0,55	13,02
INDICATOR	B	OK	B	B	B	OK	A	OK	B	B	A

SYMBOL	*Fe*	*Mn*	*Zn*	*B*	*S*	*Fe/Mn*	*Ca/Mg*	*Mg/K*	*Ca+Mg/K*	*Suma Bases*
UNIT	ppm	ppm	ppm	ppm	ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
RESULT	416,2	6,77	3,1	0,12	18,9	61,48	27,09	0,15	1,97	16,9
INDICATOR	A	OK	OK	B	OK	A	A	B	B	OK

Textura				
			A: high;	
SAND	LIMO	ARCILLA	**B:** low;	**meq/100g:** miliequivalents per hundred grams
64	28	8	**OK:** adecuate	**uds:** units;
FRANCO ARENOSO			**m/g:** miligrams per liter;	**%:** porcentaje

Source: Own elaboration

Table 13.
Average harvested stem length in alstroemeria cultivation

No.	Treatments	Dose (L/ha)	m
2.	Microorganisms	2	1.21 a
3.	Microorganisms	3	1.09 ab
1.	Microorganisms	1	0.70 ab
4.	Absolute Control	0	0.65 b
C.V. (%) 8.8			

Averages with the same letter do not differ statistically according to Tukey's test at 5%.
Source: own elaboration

In T4 a P value of 44.33 ppm is observed, indicating that 113.67 ppm of P were solubilized.

3.2 Harvested stem length

The ANOVA (Table 13) revealed highly significant differences among treatments, doses, and the control vs. the rest; however, there was no difference for microorganisms or the interaction (Microorganisms x Dose). The Coefficient of Variation (CV) was 14.9%, with an average of 0.913 m. The highest value was observed with the application of efficient microorganisms at a dose of 2 L/ha, with a value of 1.21 m, being statistically superior to the other treatments.

3.3 Economic analysis

According to the economic analysis of the treatments (Table. 14), T2 (efficient microorganisms, at a dose of 2 L/ha) could improve income and production of Alstroemeria cultivation, as it presented the best benefit compared to the other treatments.

Additionally, a net profit of 2,560 USD/production cycle/ha was obtained. T1 and T4 had lower production costs, but also lower net profits. T3 had higher production costs than T2, and its net profit was higher than T1 and T4, but lower than T2.

3.4 Discussion

This research determined that stem length was greater with the application of efficient microorganisms at a concentration 2 L/ha. The significance lack for the microorganism by dose interaction, according to [14,17] and [16, 18], can be attributed to the fact that microorganisms release and make available existing elements in the soil; after this stage, microorganisms behave similarly regardless of their quantity in the soil, because once their work is done, they perform another function, which is to stimulate plant growth and development.

The concentration of microorganisms per liter of commercial product (GEOFIX) was analyzed, showing the presence of the following quantities of microorganisms in Colony Forming Units per milliliter (CFU/ml):

1 x 10^{12} CFU/ml of Azospirillum

1 x 10^{12} CFU/ml of Azotobacter;

1 x 10^{12} CFU/ml of Rhizobium,

1 x 10^{12} CFU/ml of Pseudomonas fluorescens

[17] and [19, 20] determined that microorganisms are capable of producing an enzyme that makes atmospheric N uptake more effective.

Regarding the number of shoots per experimental unit, the highest value was also achieved with the application of efficient microorganisms at a dose of 2 L/ha. This significance is attributed to the fact that microorganisms stimulate the production of auxins, cytokinins, and gibberellins, which act as growth regulators and aid in the production of this variable, helping to increase sprouting [7,20] and [10,21] established that

Azotobacter, Azospirillum, and Rhizobium work well together and have good mobility in the soil, stimulating plant growth and nutrient availability, thereby improving yields [21].

These efficient microorganisms, incorporated into the soil via drench once a week, fixed 333.64 ppm of N, according to soil analysis results, demonstrating that microorganisms help maintain adequate soil fertility and make nutrients available for plant uptake according to their needs and requirements. According to [18] and [19] this is because Rhizobium bacteria form nodules in roots to capture and fix atmospheric N, while Azotobacter and Azospirillum have the ability to adhere to roots and fix N, stimulating growth.

According to soil analysis results, 110.28 ppm of P were solubilized with the application of Geofix, which contains

Pseudomonas fluorescens in its composition.

According to the same author, this is because these types of microorganisms are characterized by producing acids and enzymes that help regulate soil pH and thus solubilize P retained in soil colloids, making it available to the plant.

Finally, the economic analysis of the treatments shows that the application of efficient microorganisms at a dose of 2 L/ha is the most recommended for improving Alstroemeria cultivation production and, consequently, the economic income of growers, as it presents a net benefit of 2,560 USD/ha, which is superior to other treatments and the control.

Table 14.
Economic analysis of the evaluated treatments

Trat	Organic Amendment	Dose (L/ha)	Yield (stems/ha)	Production Value (USD)	Production Costs (USD)	Net Benefit (USD)
				Fixed	**Variables**	**Total**
T1	Microorganisms	1	70,000	4,200	3,200	120
T2	Microorganisms	2	100,000	6,000	3,200	240
T3	Microorganisms	3	80,000	4,800	3,200	360
T4	Control	0	60,000	3,600	3,200	0

Alstroemeria stem value: 0.06 USD; Microorganism cost: 10 USD/L.
Source: own elaboration

4 Conclusions

The treatment that yielded the best results in terms of crop quality and yield was the weekly application of efficient microorganisms at a dose of 2 L/ha, achieving a N fixation of 335.48 ppm.

A N fixation of 333.64 ppm was achieved, compared to the Control (T4) which reported a content of 1.48 ppm of N.

Beneficial microorganisms, Azotobacter, Rhizobium, Azospirillum, and Pseudomonas fluorescens, help improve soil fertility.

T2 performed best in terms of P solubilization, with a value of 47.72 ppm.

110.28 ppm of P were solubilized, considering that at the beginning of the investigation, 158.4 ppm of P was fixed in this soil.

The 2 L/ha dose of efficient microorganisms showed the best results in terms of stem length, reporting sizes of 1.21 m, unlike the control which reported a length of 0.65 m.

The highest number of shoots/m² was achieved with the application of Geofix at a dose of 2 L/ha, with a sprouting of 10 stems/m² compared to the control which presented only 6 shoots/m².

It was established that the best method to inoculate efficient microorganisms into the soil and improve the quality and yield of alstroemeria cultivation was weekly application directly to the plants via drench.

The application of efficient microorganisms at a dose of 2 L/ha presented the highest net economic benefit, with a value of 2,560 USD/ha.

With this additional N incorporation, the net cost-benefit of the control would leave a value of 184 USD/ha.

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