Economic feasibility of *Gluconacetobacter diazotrophicus* in carrot cultivation

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ABSTRACT

The inclusion of more sustainable alternatives such as bacterial inoculants is a viable option for the competitiveness of vegetable crops in tropical countries such as Colombia. The economic feasibility of a bacterial suspension of *G. diazotrophicus* applied to the carrot crop was determined. The native isolate *G. diazotrophicus* GIBI029 was evaluated and the strain ATCC 49037 was used as a control. The experiment was installed in a subdivided plot design, where the plot was the bacterium *G. diazotrophicus* (ATCC49037 and GIBI029. The subplot was the concentration of *G. diazotrophicus* (88×10^6 CFU/mL and 18×10^7 CFU/mL) and, in it, the levels of nitrogen and phosphorus (0% and 100% nitrogen and phosphorus) were assorted. The average weight of the carrot (g) and the yield by quality of the consuming organ (kg/ha) were evaluated. Through the production cycle, fixed, variable, and total costs were calculated. Benefit / cost ratios higher than 1.46 and net income up to US$ 10,817/ha were achieved. It is possible to efficiently and economically use the native isolate *G. diazotrophicus* GIBI029 in the search for more sustainable and competitive cultural practices.

Keywords: diazotrophic bacteria; plant growth promoter; benefit / cost ratio.

INTRODUCTION

The carrot is one of the most consumed vegetables worldwide. The world production of carrots reached 39,996,287 t in 2018, corresponding to a total cultivated area of 1,131,049 ha (Faostat, 2020). Carrot production in Colombia is very expensive due to the high price of fertilizers: approximately 25% of the total costs are destined to the nutrition of the crop.

In the case of carrot cultivation, the Colombian farmer cannot compete with foreign producers, since imports of this vegetable present reduced purchase charges and have low product distribution tariffs. In general, the Colombian agricultural sector is unaware of the use of new, cheaper fertilization strategies such as the use of biofertilizers, which could affect the final marketing price.

The development of biofertilizers traditionally focused on the production of *Rhizobium* for its application in legume crops, especially soybeans; however, other alternatives are currently being explored through the development of inoculants based on autochthonous nitrogen-fixing bacteria such as those of the genera *Herbaspirillum* and *Gluconacetobacter*.

In particular, the bacterium *G. diazotrophicus* exhibits important properties to promote plant growth, as has been demonstrated by Beneduzi *et al.* (2013) and in a previous work (Restrepo *et al.*, 2017). *G. diazotrophicus* has the potential to provide the farmer with benefits such as the production of phytohormones of both auxins and gibberellins in significant quantities to allow an efficient and profitable growth system (Figueroa-Viramontes *et al.*, 2011). Additionally, it has been detected in grass plants that these microorganisms have the ability to naturally solubilize micronutrients such as phosphorus, zinc, iron, potassium, and magnesium (Eshaghi *et al.*, 2019). This solubilization property is especially important in the case of phosphorus, since although high amounts

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of phosphorous fertilizers are applied to cultivable soils in the world, a large part of this micronutrient is fixed or immobilized in the soil, preventing its assimilation by plants (Santos *et al*., 2019; Paredes-Villanueva *et al*., 2020; Vejan *et al*., 2016). Precisely, *G. diazotrophicus* exhibits a significant capacity to solubilize phosphates (Restrepo *et al*., 2017), which represents an important characteristic for a wide range of economically important crops.

Evaluations of native isolates of *G. diazotrophicus* have been carried out in various crops such as sugar cane (Ferreira *et al*., 2019), cassava and papaya (Dibut *et al*., 2010), and tomato (Fernández-Delgado *et al*., 2019), which have shown a positive effect on growth promotion, making it possible to reduce the use of chemical fertilizers. However, no published articles were found in the available literature on the evaluation of growth promotion by *G. diazotrophicus* in carrot crops. Nevertheless, the economic analysis of the possibility of implementing a technological package that includes the use of this bacterium for the fertilization of carrot crops has not been carried out so far. Consequently, the present investigation aimed at determining the economic feasibility of using a bacterial suspension of *G. diazotrophicus* in promoting carrot growth.

MATERIALS AND METHODS

Location

This study was carried out at the Tesorito Farm of the University of Caldas at an altitude of 2,340 masl (5°01’49"N and -75°26’13" W), annual rainfall of 1,800 mm, relative humidity of 78%, solar brightness of 1,215 h-light per year, average temperature of 17.5 °C and sandy loam type of soil (Universidad de Caldas, 2014).

Microorganism

The native isolate of the bacterium *G. diazotrophicus* GIBI029 from sugar cane was evaluated. The standard strain *G. diazotrophicus* ATCC 49037 was used as a control of the experiments. The native bacterial isolate come from the Microorganisms Collection of the Universidad Católica de Manizales and are covered by the Permit for the Collection of Wild Specimens of Biological Diversity Framework for non-commercial scientific research purposes No. 1166, issued by the Environmental Authority of Environmental Licenses of Colombia (ANLA) to the Universidad de Caldas.

Preparation of G. diazotrophicus cell suspension

The preparation of the inoculum and bacterial suspension of *G. diazotrophicus* was carried out using the modified DYGS (Silva *et al*., 2016) and LGI-PN (Sadeghi & Khodakaramian, 2020) media. The media were inoculated and incubated at 30 ºC under constant shaking at 150 rpm for 7 days and were evaluated daily until reaching each of the required bacterial concentrations (88×10^6 and 18×10^7 CFU/mL). During this period, the purity, viability, and concentration of the bacteria were verified through the technique of Colony Forming Units per milliliter (Ahmad *et al*., 2016).

Experimental design

An experimental design of sub-subdivided plots was used. The largest plot was made up of the bacterium *G. diazotrophicus* (ATCC49037 strain and GIBI029 isolate), and the following bacterial concentrations were arranged in the subplots: 88×10^6 CFU/mL and 18×10^7 CFU/mL (Restrepo, 2014). In the subplots, the nitrogen and phosphorus levels were assorted in two combinations: With and without the joint addition of nitrogen and phosphorus (0% and 100% of nitrogen and phosphorus). Nitrogen fertilization consisted of the addition of 200 kg/ha urea while phosphorous fertilization consisted of the addition of 1000 mL/ha phosphoric acid. In all cases, 120 kg/ha KCl and 80 kg/ha $MgSO_4$ were added. The number of replicas per combination was 4 blocks. The experimental unit was 12.3 m2. In each experimental unit (block) a minimum of 70 carrot plants will be guaranteed. The combinations of the treatments and their coding are presented in Table 1. The variables evaluated to know the effect of the application of *G. diazotrophicus* in carrot plants were average carrot weight (in g) and yield (kg/ha), taking into account the qualities according to the weight reached by the consuming organ. The quality grades of the carrot crop consumption organ were defined according to the following classification: Extra quality, greater than 120 g; first quality, 90-119 g; second quality, 70-89 g; third quality, 30-69 g; less than 30 g, lower quality equivalent to losses) (Szel¹g-Sikora *et al*., 2019).

In-field establishment of treatments

The establishment and management of the culture was carried out according to the protocols described by Szelag-Sikora *et al*. (2019). Ten days after sowing (days), it was applied to each experimental unit or plot, with the corresponding treatment in foliar spray at the inoculated rate of 200 mL of bacterial suspension according to the treatments and concentrations described in the experimental design.

Evaluation of economic feasibility

The economic feasibility was assessed through individual calculation applying the feasibility analysis approach reported by Herrera *et al*. (2016). The value of the *G. diazotrophicus* suspension was estimated at a value of 231 US dollars (US$), corresponding to the commercial value of a liquid inoculant of the bacterium in one-liter presentation (ATCC, 2020). Likewise, the costs of the different types of fertilization according to the established treatments were taken into account. To carry out the economic analysis, the formats adopted by the Corporación Colombia Internacional and DANE (DANE, 2017) were taken into account. The average value of carrots was estimated for the last 10 years (2010-2020) (Corabastos, 2020). The average commercial value was US$ 0.34/kg, discriminated as follows: extra US$ 0.49/kg, first US$ 0.43/kg, second US$ 0.26/kg, and third US$ 0.20/kg (Corabastos, 2020). Finally, the following financial indicators were calculated according to Arbelaez *et al*. (2016): Gross and net income, direct, indirect and total production costs, unit production margin (UPM), and benefit/cost ratio (B/C R). Analysis of variance and Duncan's test were performed considering a p-value < 0.05. For this, the GLM program of SAS version 9.1 (SAS Institute, Inc., USA) was used.

RESULTS AND DISCUSSION

In the evaluation of the yields, statistically significant differences (p dH 0.05) were observed between the different treatments (Tables 1 and 2). In all cases, the application of the high level of concentration (*d2* =18x10^7 CFU/mL) of the evaluated bacterial suspensions showed yields higher than 30,345 kg/ha, as in the case of treatment with the standard ATCC strain with 100 % fertilization (see treatment ATCC-*d2*-100NP in Table 1) that was above the absolute control without the addition of nitrogenous and phosphorous fertilizers (Control-0NP) and the commercial control to which was applied 100% of this type of fertilization (Control-100NP).

For the native isolation at the *d2* concentration with or without the addition of nitrogenous and phosphate fertilizers, yields not showing statistically significant differences were obtained compared to that achieved with the ATCC 49037 strain applied with this same concentration with 0% fertilization. This latter treatment exhibited the highest yield of those evaluated in this work (37,867 kg/ha). With the values reached, the national average carrot yield (27,170 kg / ha) and the average yield in the department (administrative division in Colombia equivalent to a province) of Caldas (14,500 kg/ha) were exceeded for the year 2017 (Agronet, 2020). These data indicate an added value of approximately 15,000 kg / ha.

The greatest losses in harvest of the consuming organ were presented in the treatments with the low level of the application concentrations of the bacterial suspensions (*d1* = 88×10^6 CFU/mL) for both strain types (see last column in Table 1). The treatment that used the native isolate of *G. diazotrophicus* at a low concentration without application of additional fertilization presented the lowest performance of those evaluated and presented statistically significant differences (p < 0.05) with respect to the treatment with the highest value of performance (coded as ATCC-*d2*-0NP) as observed in Table 1.

Table 1: Overall yield and distribution of yield by quality grades for Royal Chantenay carrot depending on the type of strain and applied concentration of *G. diazotrophicus* and the addition or not of nitrogenous and phosphorous fertilizers

Strain	Concentration (CFU/mL)	Fertilization (%)	Code	Yield (kg/ha)					
					Global	Extra	First	Second	Third
Loss									
-	0	0	Control-0NP	28,290^{ab}	2,946^{bc}	16,350^{a}	5,561^{cd}	2,946^{cd}	487^{a}
-	0	100	Control-100NP	27,901^{ab}	2,663^{bc}	10,880^{abcd}	10,728^{abc}	2,739^{cd}	891^{a}
ATCC 49037	18.0×10^7	0	ATCC-*d2*-0NP	37,867^{a}	14,967^{a}	14.967^{a}	0^{e}	7,484^{abcd}	449^{a}
GIBI029	18.0×10^7	0	GIBI-*d2*-0NP	31,430^{ab}	6,121^{b}	6,121^{cde}	12,243^{ab}	6,121^{bcde}	823^{a}
ATCC 49037	18.0×10^7	100	ATCC-*d2*-100NP	30,345^{ab}	6,069^{b}	6,069^{cde}	12,138^{ab}	6,069^{bcde}	0^{b}
GIBI029	18.0×10^7	100	GIBI-*d2*-100NP	31,597^{ab}	6,320^{b}	6,320^{cde}	12,639^{ab}	6,320^{abc}	0^{b}
ATCC 49037	8.8×10^7	0	ATCC-*d1*-0NP	24,199^{ab}	0^{d}	6,069^{de}	13,563^{a}	4,521^{bcd}	1,594^{a}
ATCC 49037	8.8×10^7	100	ATCC-*d1*-100NP	23,533^{ab}	0^{d}	13,208^{ab}	4,403^{cd}	4,403^{bcd}	1,520^{a}
GIBI029	8.8×10^7	0	GIBI-*d1*-0NP	18,316^{b}	0^{d}	3,412^{e}	3,412^{d}	10,235^{ab}	1,258^{a}
GIBI029	8.8×10^7	100	GIBI-*d1*-100NP	19,828^{ab}	0^{d}	3,859^{de}	3,859^{d}	11,578^{ab}	532^{a}

Observations: Values with different letters in the same column exhibit statistically significant differences (p < 0.05) according to Duncan's test.

Table 2: Structure of production costs (in US$/ha) of the Royal Chantenay variety of the carrot crop with the application of *G. diazotrophicus* as growth promoter

Treatment	**Control-0NP**		**Control-100NP**		**ATCC-*d2*-0NP**		**GIBI-*d2*-0NP**		**ATCC-*d2*-100NP**	
Concept	**Total value**	**% share**	**Total value**	**% share**	**Total value**	**% share**	**Total value**	**% share**	**Total value**	**% share**
A. Labor (1+2+3+4)	1,296	35.54	1,296	32.71	1,871	42.62	1,553	38.14	1,499	34.59
(1) Land adaptation	241	6.61	241	6.08	440	10.01	365	8.96	352	8.13
Preparation and sowing	241	6.61	241	6.08	327	7.45	271	6.66	262	6.04
Application of the bacteria to the sowing	0	0.00	0	0.00	113	2.57	94	2.30	90	2.08
(2) Crop maintenance	407	11.16	407	10.27	552	12.58	458	11.26	443	10.21
Cultivation work	299	8.20	299	7.55	406	9.24	337	8.27	325	7.50
Application of inputs	108	2.96	108	2.73	147	3.34	122	2.99	117	2.71
(3) Harvest	482	13.21	482	12.16	654	14.89	543	13.32	524	12.09
(4) Post-harvest	166	4.56	166	4.19	225	5.13	187	4.59	181	4.17
B. Inputs (5+6+7+8+9+10+11+12+13+14)	1,825	50.07	2,141	54.06	1,995	45.44	1,995	48.99	2,311	53.31
(5) Seed	599	16.44	599	15.13	599	13.65	599	14.72	599	13.83
(6) Amendment	29	0.79	29	0.73	29	0.66	29	0.71	29	0.67
(7) Organic fertilizer	191	5.25	191	4.83	191	4.36	191	4.70	191	4.41
(8) Edaphic fertilizer	292	8.00	608	15.34	292	6.64	292	7.16	608	14.02
(9) *G. diazotrophicus* suspension	0	0.00	0	0.00	231	5.26	231	5.67	231	5.32
(10) Fungicide	41	1.11	41	1.02	0	0.00	0	0.00	0	0.00
(11) Insecticide	18	0.49	18	0.45	0	0.00	0	0.00	0	0.00
(12) Herbicide	3	0.07	3	0.07	0	0.00	0	0.00	0	0.00
(13) Package	327	8.96	327	8.25	327	7.44	327	8.02	327	7.53
(14) Bundle	327	8.96	327	8.25	327	7.44	327	8.02	327	7.53
Direct cost (A+B)	3,121	85.62	3,437	86.76	3,866	88.06	3,548	87.12	3,810	87.90
C. Indirect cost (15+16+17)	524	14.38	524	13.24	524	11.94	524	12.88	524	12.10
(15) Rent	229	6.28	229	5.78	229	5.21	229	5.62	229	5.28
(16) Administration	111	3.04	111	2.80	111	2.52	111	2.72	111	2.56
(17) Incidentals	185	5.07	185	4.66	185	4.21	185	4.54	185	4.26
Total (A+B+C)	3,645	100.00	3,961	100.00	4,390	100.00	4,072	100.00	4,335	100.00

Remarks: Coding of the treatments are deciphered in Table 1.

Continuation of Table 2.

Treatment	GIBI-*d2*-100NP		ATCC-*d1*-0NP		ATCC-*d1*-100NP		GIBI-*d1*-0NP		GIBI-*d1*-100NP	
Concept	**Total value**	**% share**	**Total value**	**% share**	**Total value**	**% share**	**Total value**	**% share**	**Total value**	**% share**
A. Labor (1+2+3+4)	1,550	35.34	1,196	32.19	1,163	29.09	905	26.43	980	25.68
(1) Land adaptation	364	8.30	281	7.56	273	6.83	213	6.21	230	6.03
Preparation and sowing	271	6.17	209	5.62	203	5.08	158	4.62	171	4.49
Application of the bacteria to the sowing	93	2.13	72	1.94	70	1.75	55	1.59	59	1.55
(2) Crop maintenance	457	10.43	353	9.50	343	8.59	267	7.80	289	7.58
Cultivation work	336	7.66	259	6.98	252	6.31	196	5.73	212	5.57
Application of inputs	121	2.77	94	2.52	91	2.28	71	2.07	77	2.01
(3) Harvest	541	12.35	418	11.25	406	10.16	316	9.23	342	8.97
(4) Post-harvest	187	4.26	144	3.88	140	3.50	109	3.18	118	3.09
B. Inputs (5+6+7+8+9+10+11+12+13+14)	2,311	52.70	1,995	53.70	2,311	57.80	1,995	58.26	2,311	60.57
(5) Seed	599	13.67	599	16.13	599	14.99	599	17.50	599	15.71
(6) Amendment	29	0.66	29	0.78	29	0.72	29	0.84	29	0.76
(7) Organic fertilizer	191	4.36	191	5.15	191	4.78	191	5.58	191	5.01
(8) Edaphic fertilizer	608	13.86	292	7.85	608	15.20	292	8.52	608	15.93
(9) *G. diazotrophicus* Suspension	231	5.26	231	6.21	231	5.77	231	6.74	231	6.05
(10) Fungicide	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
(11) Insecticide	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
(12) Herbicide	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
(13) Package	327	7.45	327	8.79	327	8.17	327	9.54	327	8.56
(14) Bundle	327	7.45	327	8.79	327	8.17	327	9.54	327	8.56
Direct cost (A+B)	3,861	88.04	3,191	85.89	3,474	86.89	2,900	84.69	3,291	86.26
C. Indirect cost (15+16+17)	524	11.96	524	14.11	524	13.11	524	15.31	524	13.74
(15) Rent	229	5.22	229	6.16	229	5.72	229	6.68	229	6.00
(16) Administration	111	2.53	111	2.98	111	2.77	111	3.24	111	2.91
(17) Incidentals	185	4.21	185	4.97	185	4.62	185	5.39	185	4.84
Total (A+B+C)	4,385	100.00	3,715	100.00	3,998	100.00	3,424	100.00	3,815	100.00

Remarks: Coding of the treatments are deciphered in Table 1.

In general, the two types of *G. diazotrophicus* strain in the highest concentration proved to be more effective compared to the commercial control (conventional treatment used by the farmer), which allows the design of different production alternatives to the conventional ones by incorporating biotechnological products such as plant-growth promoting microbial inoculants.

Boskovic-Rakocevic *et al*. (2012), when evaluating four doses of nitrogen fertilization (0, 60, 120 and 180 kg/ha) found that the content of ß-carotene increased with increasing rates of nitrogen and it was found that it was statistically significant even at 120 and 180 kg/ha N, compared to the control and the lowest dose of 60 kg/ha. The results of this work highlight the importance of the use of *G. diazotrophicus* in its highest concentration, which allowed a synergistic action with the level of fertilization applied, resulting in positive effects on crop quality and yield. In this sense, the physical-chemical and biological characteristics of the soil must be evaluated in order to guarantee the sustainability of the productive systems, as evidenced in this study, which used optimal levels of nitrogen (0.68 %) and phosphorus (89 ppm) in the soil reported in the laboratory soil analysis at the beginning of the trial, reaching the best yields in the crop cycle evaluated. However, it would be difficult to sustain this type of response over time if a proportion of nutrients equivalent to the extraction of the crop is not returned to the soil or growth promotion strategies such as the application of the bacterium *G. diazotrophicus* are not used in the highest concentration evaluated that demonstrated the best yields even without the addition of nitrogenous and phosphate sources.

It should be noted that although the initial phosphorus contents (89 ppm) in the study site are high, due to the characteristics of the soil thanks to the presence of allophane clay, there is a high retention of said element, reducing its availability for the plant. In this regard, the phosphate solubilization properties tested for *G. diazotrophicus* (Restrepo *et al*., 2017) make possible to avoid additional applications of phosphate fertilizers while preserving optimal crop yields and economic feasibility.

Cruz-Tobar *et al*. (2018), showed that carrots have a low response to nitrogen, phosphorus, potassium, and manure in soils where the main rotation crop was potatoes due to the residual effect of fertilizers applied in high doses to the crop, obtaining a second quality production. This situation was not observed in this study, despite the fact that there was a similar rotation. In addition, the use of 100% nitrogen and potassium fertilization allowed those authors to obtain a mostly first quality crop. Similarly, it was shown that the use of only *G. diazotrophicus* without any addition of nitrogen and phosphorus resulted in the best carrot weight (126.48 g), obtaining a very good quality harvest, as long as the nitrogen and phosphorus levels in the soil are suitable for the cultivation of this vegetable.

Regarding the production costs of the carrot crop according to the conditions of Caldas in Colombia, an investment in 115 days equivalent to the crop cycle was estimated (Table 2). The values are expressed in US dollars per hectare during the investment period. The inoculations of the native isolate *G. diazotrophicus* for the *d1* concentration with and without the addition of nitrogenous and phosphorus fertilization were the ones with the lowest share of the harvest labor in the total costs with 28.89% and 30.55 %, respectively (Tables 1 and 2).

The production costs for one hectare in each of the bacterial inoculates differ until the beginning of the harvest because both the cultural tasks and the inputs used present differential costs (fertilization and labor). The main variation occurred in the labor category, specifically associated with harvesting tasks, due to the fluctuation of productivity that was evidenced in each of the evaluated treatments. Likewise, a fluctuation in inputs is evidenced due to the cost of the inoculants (Table 2). During the estimation of the total costs per hectare, the following parameters were taken into account: labor costs, supplies, and the cost of bacterial suspensions

The highest production cost (US$ 4,390/ha) corresponded to the use of the standard strain at the *d2* concentration with and without fertilization with nitrogen and phosphorus (Table 2). In these treatments, the participation of labor was high in relation to total costs (42.62%) and based on the yield obtained (37,867 kg/ha) (Tables 1 and 2).

One of the items with the highest share in production costs for all evaluated treatments (including controls) was labor, which ranged between 45.65% and 28.89% of total production costs. Within the item of labor, cultural tasks are those with the highest participation due to the slope conditions of the terrain (eH 5%) present in the study area, which requires that each one of the tasks is done manually. Finally, the share percentages of bacterial suspensions at the concentration of 8.8×10^7 CFU/mL have an upward behavior in production costs (labor and supplies) and a downward behavior for the harvest, taking into account that the latter is concentrated. In turn, the treatments with this concentration present a lower yield than the controls.

The carrot crop where the strain ATCC 49037 was applied at the *d2* concentration without nitrogenous and phosphate fertilization presents the best gross revenue (US$ 15,208/ha), followed by the treatments with application of the native isolate with and without nitrogenous and phosphate fertilization, which presented gross incomes between US$ 10,000 and US$ 10,500 per hectare, along with the control treatment without fertilization (Table 3). The treatments that used bacterial inoculants of *G. diazotrophicus* at a concentration of

Table 3: Economic analysis of the carrot crop in the presence of *G. diazotrophicus* with and without nitrogen and phosphate fertilization under the conditions of Caldas (Colombia)

Treatment	Production costs (US$/ha)	Revenue per quality (US$/ha)				Revenue (US$/ha)		UPM (US$/kg)	B/C R
		Extra	First	Second	Third	Gross	Net		
Control-0NP	3,645	1,448	6,967	1,458	579	10,453	6,807	0.13	1.87
Control-100NP	3,961	1,309	4,636	2,813	539	9,297	5,336	0.14	1.35
ATCC-*d2*-0NP	4,390	7,358	6,377	0	1,472	15,208	10,817	0.12	2.46
GIBI-*d2*-0NP	4,072	3,009	2,608	3,210	1,204	10,031	5,959	0.13	1.46
ATCC-*d2*-100NP	4,335	2,984	2,586	3,183	1,194	9,946	5,611	0.14	1.29
GIBI-*d2*-100NP	4,385	3,107	2,693	3,314	1,243	10,357	5,972	0.14	1.36
ATCC-*d1*-0NP	3,715	0	2,586	3,556	889	7,031	3,316	0.15	0.89
ATCC-*d1*-100NP	3,998	0	5,628	1,155	866	7,648	3,650	0.17	0.91
GIBI-*d1*-0NP	3,424	0	1,454	895	2,013	4,361	937	0.19	0.27
GIBI-*d1*-100NP	3,815	0	1,644	1,012	2,277	4,933	1,118	0.19	0.29

UPM: unit production margin; B/C R: benefit/cost ratio.

8.8×10^7 CFU/mL, regardless of whether or not they have nitrogenous and phosphate fertilization, are the ones with the lowest yield and, consequently, those that exhibit the lowest gross income, making them financially unattractive.

The lowest unit production margin (0.12 U$/kg) was obtained for the treatment with the strain ATCC 49037 applied at the high level of concentration (18×10^7 CFU / mL) without fertilization, while the UPM of the commercial control (farmer's conventional treatment with 100% fertilization) was US$ 0.14/kg. This constitutes a competitive advantage for the farmer who decides to apply *G. diazotrophicus* as a growth promoter, due to the fact that having a low UPM, considered as the minimum value at which the farmer can sell the product in the market to recover the investment (constituting the equilibrium point) and having a low price, the producer will have more opportunities to market it, without presenting direct competition with other producers (Table 3). In this way, the estimated UPM values that were below US$ 0.14/kg present an equilibrium point suitable for an adequate profit margin in the production system. Within this range, the bacterial suspensions of both strain types with concentrations of 18×10^7 CFU / mL with and without the nitrogenous and phosphate fertilization are found. The bacterial suspensions with concentrations of 8.8×10^7 CFU/mL presented higher values in the UPM of US$ 0.17/kg, which is equivalent to the value perceived in the market for the product, making these introductions financially unviable (Table 3).

According to the benefit/cost ratio calculated by the adopted assessment (Table 3), the bacterial suspensions applied at high concentrations with and without the nitrogenous and phosphate fertilization showed the highest profitability along with the control treatment without fertilization, standing out as financially attractive for an investor in this type of production system. On the other hand, the bacterial suspensions applied at low concentration do not exceed the investors' perspectives, making the profitability of the crop unfeasible. For the benefit/cost ratio, the treatment with the use of the standard strain at a concentration of *d2* without fertilization presented the highest B/C R (for every dollar invested, the farmer receives US$ 2.46 gross), followed by the treatments with this same concentration for the native isolate without fertilization and the standard strain with nitrogenous and phosphate fertilization (see Table 3). The lowest relationships were reported again for the treatments with the isolate GIBI029 at the *d1* concentration without and with fertilization (0.27 and 0.29, respectively).

CONCLUSIONS

The use of the diazotrophic bacterium *G. diazotrophicus* (standard and native strains) in suspensions with concentrations of 18×10^7 CFU/mL in carrot crops makes possible to significantly improve their economic feasibility, reaching yields of up to 37,417 kg/ha, even in the case of no addition of nitrogenous and phosphate fertilizers, as long as the soil contains the required levels of these nutrients.

The results obtained in this work indicate that benefit/cost ratios higher than 1.46 and net income of up to US$ 10,817/ha can be achieved. In particular, the possibility of using the Colombian native isolation GIBI029 of *G. diazotrophicus* in an economically efficient way was demonstrated in the search for more sustainable and competitive cultural practices.

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