Cultivos Tropicales, Vol. 46, No. 4, October-December 2025, e-ISSN: 1819-4087, p-ISSN: 0258-5936, https://ediciones.inca.edu.cu

Cu-ID: https://cu-id.com/2050/v46n4e01

Original Article

Impact assessment through economic indicators on diversified farms in the Mayabeque province

Evaluación del impacto a través de indicadores económicos en fincas diversificadas de la provincia Mayabeque

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ABSTRACT: The combined use of mycorrhizal fungi (AMF) inoculant and chitosan biostimulant was used in this research to improve the production process, to evaluate the impact of this technology through economic indicators in diversified production systems in Mayabeque province. The valuations were developed in the production areas of the farms "La Chivería", "El Mulato", "San Miguel" and "Santa Catalina". Two treatments were evaluated: 1) Traditional management carried out by farmers on their crops 2) Traditional management plus the joint application of AMF inoculant by coating the seeds in sowing and the application of chitosans sprinkled with the recommended dose and time. From the data obtained, the value and costs of production per hectare were calculated, as well as the economic benefits obtained and the ratio between them. The results showed that, although the implementation of this technology was executed with a greater monetary investment, it allowed to reach higher levels in terms of agricultural yields, which provided an increase in the value of production and a higher benefit/cost ratio compared to traditional treatment.

Key words: inoculant, biostimulant, technology, benefit.

RESUMEN: El empleo combinado del inoculante a base de hongos micorrízicos arbusculares (HMA) y el bioestimulante de quitosanas fue utilizado en esta investigación para la mejora del proceso productivo, con el objetivo de evaluar el impacto de esta tecnología a través de indicadores económicos en sistemas productivos diversificados en la provincia Mayabeque. Las valoraciones se desarrollaron en las áreas de producción de las fincas "La Chivería", "El Mulato", "San Miguel" y "Santa Catalina".. Fueron evaluados dos tratamientos: 1) Manejo tradicional que realizan los agricultores a sus cultivos 2) Manejo tradicional más la aplicación conjunta del inoculante de HMA por recubrimiento de las semillas en la siembra y la aplicación de quitosanas asperjadas con la dosis y momento recomendado. A partir de los datos obtenidos, se calculó el valor y los costos de producción por hectárea, así como los beneficios económicos obtenidos y la relación que existe entre ambos. Los resultados mostraron que, aunque con la implementación de esta tecnología se ejecutó con una mayor inversión monetaria, permitió alcanzar niveles superiores en cuanto a los rendimientos agrícolas, lo que proporcionó un incremento en el valor de la producción y una mayor relación beneficio/costo con respecto al tratamiento tradicional.

Palabras clave: inoculante, bioestimulante, tecnología, beneficio.

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Received: 11/11/2024

Accepted: 23/01/2025

Conflicts of interest: Authors declare that there are no conflicts of interest

Authors' contribution: Ilen Miranda Mora and Clara María Trujillo Rodríguez: studied and analyzed the conceptual elements related to the introduction and methodology. Collaborated in the review of bibliographic references. They participated in the critical and final review of the draft article. Gloria Marta Martín Alonso, Luis Roberto Fundora Sánchez and Ramón Antonio Rivera Espinosa: contributed to the assembly of the experiments, the collection of experimental data in field conditions, discussion of the research results, as well as the conclusions. They participated in the critical and final review of the draft article.

INTRODUCTION

Impact assessment through economic indicators is vital both nationally and internationally. This is to determine the relevance of the objectives, degree of achievement, efficiency, effectiveness, impact and feasibility of programs, projects and actions of different nature aimed at transforming contexts for their development (1,2). The results are used both to approve the implementation of these, based on the demonstration of the potential impact (ex ante evaluation), and to assess what finally happened in practice, some time after the actions have been put into operation (ex post evaluation) (3).

Among the types of impact assessment, the economic one is the oldest and best known for assessing the impact of projects. It is defined as a procedure or method, in both cases the intention is to measure the consequences and the beneficial results that are produced by the investments, through the analysis of different indicators that facilitate the adoption of rational decisions (4).

Although a wide variety of indicators can be used in economic impact assessment, the best known are associated with costs and profits. Therefore, the economic impact assessment could be summarized as the process of comparative analysis that assesses the extent to which an intervention produced lasting changes in economic costs or benefits (5).

These analyses highlight the economic indicators: production value, production costs, profit obtained and the profit/cost ratio (P/C). Each clearly reflects the behavior of the main economic, financial and monetary variables, which directly affect or favor the activities that are developed in the productive systems. They are the ones that provide the level of income or expenses, finally determining the social situation and living standards of peasant families (6,7).

In this sense, the value of production measures the quantity actually produced, based on sales. Production costs, meanwhile, are related to the production process and are quantifiable for decision-making. They must provide as much information as possible in order to reduce risks (8).

On the other hand, profit is defined as the gain obtained from an investment or commercial activity. To calculate it, the cost of the problem and that of the solution must be determined. The latter is an expression to designate the profit obtained in a given activity. The value of the benefit is obtained by deducting the costs from the income. Consequently, the profit/cost ratio is a financial tool that measures the relationship between the costs and benefits associated with an investment project in order to evaluate its profitability. The investment project is understood not only as the creation of a new business, but also as investments that can be made in a going concern, such as the development of new products or the acquisition of new machinery for infrastructure (9).

Therefore, the development and application of bioproducts (biopesticides, biofertilizers and biostimulants) in agriculture is being the subject of great attention by scientists and farmers. They assume it as an alternative to reduce the use of chemical products in order to reduce the environmental pollution produced by them. They are of economic interest for promoting increases in crop yields and quality, eliminating plant pathogens and increasing soil quality (10).

In Cuba, since the 1990s, there has been intense research in the search for bioproducts from natural raw materials, which has led to the fact that, at present, there are around 21 products cataloged as biofertilizers and biostimulants. Among them is a chitosan-based biostimulant that has been recognized for its antimicrobial activity and ability to stimulate defense mechanisms in plants (11-13) and an inoculant based on arbuscular mycorrhizal fungi (14).

Although actions have been carried out to validate the sustainable management of bioproducts of Cuban origin, the degree of knowledge of the production costs of short-cycle and perennial crops with the use of inoculant based on arbuscular mycorrhizal fungi and the biostimulant of chitosans, as well as the use and appropriation of this technology by farmers, is still insufficient. This situation reveals the need to establish economic indicators that must include innovation actions for their successful dissemination.

The development and implementation of bioproducts-biopesticides, biofertilizers, and biostimulants-have attracted increasing attention from researchers and agricultural producers. These products are considered viable alternatives to reduce the use of chemical inputs, thereby mitigating environmental pollution caused by conventional agrochemicals. Bioproducts are also economically relevant due to their potential to increase crop yields and quality, eliminate plant pathogens, and improve soil health (10).

In Cuba, intensive research has been conducted since the 1990s to identify bioproducts derived from natural raw materials. As a result, approximately 21 products are currently classified as biofertilizers and biostimulants. Among these is a chitosan-based biostimulant recognized for its antimicrobial activity and its ability to stimulate plant defense mechanisms (11-13), as well as an inoculant based on arbuscular mycorrhizal fungi (14).

Although validation efforts have been undertaken regarding the sustainable management of Cuban-origin bioproducts, there remains limited knowledge about the production costs of short-cycle and perennial crops using the arbuscular mycorrhizal fungi inoculant and the chitosan-based biostimulant. Furthermore, the adoption and integration of these technologies by farmers are still insufficient. This highlights the need to establish economic indicators that incorporate innovation strategies to ensure successful dissemination.

MATERIALS AND METHODS

Four experimental areas were set up where the responses of crops were evaluated in sequence when using the bioproducts in four farms belonging to San José de las Lajas, Jaruco and Nueva Paz municipalities in Mayabeque province. These farms differ from each other in the type of soil: El Mulato and Santa Catalina (Leached Red Ferralitic), San Miguel (Carbonated Sialitic Brown) and La Chivería (Reddish Brown Fersialitic).

Table 1. Cultivation sequences in each analyzed farm

La Chivería	Sowing date	El Mulato	Sowing date	San Miguel	Sowing date	Santa Catalina	Sowing date
Beans	sep-2017	Maize	jun-2017	Beans	sep-2018	Beans	nov-2017
Pepper	dec-2017	Beans	oct-2017	Cassava /canavalia	jan-2019	Maize	apr-2018
Cassava	mar-2018	Cassava	feb-2018	Maize	nov-2019	Sweet potato	sep-2018
Garlic	nov-2018	Beans	dec-2018	Sweet potato	apr-2019	Maize	feb-2019
Maize	apr-2019	Maize	apr-2019	Canavalia	aug-2020	Beans	sep-2019
Beans	sep-2019	Cucumber	sep-2019	Garlic	nov-2020	Maize	jan-2020
Tomato	jan-2020	Beans	jan-2020	Maize	apr-2021	Fallow*	jun-2020
Maize	jun-2020	Maize	may-2020	Sweet potato	jul-2021	Beans	sep-2020
Beans	sep-2020	Tomato	sep-2020	Beans	nov-2021	Maize	jan-2021
Garlic	dec-2020	Beans	jan-2021	Sweet potato	feb-2022	Canavalia	apr-2021
Canavalia	apr-2021	Maize	jun-2021	Tomato	sep-2022	Squash	sep-2021
Tomato	aug-2021	Beans	mar-2022	Sweet potato	jan-2023	Maize	jan-2022
Beans	dec-2021			Maize	feb-2023	Barbecho	jun-2022
						Beans	sep-2022
						Tomato	nov-2022

*Fallow: weeds grown freely for a period of three months

Within the selected farms, a permanent area dedicated to short-cycle crops was chosen to evaluate the effect of the proposed management on yields and some physical properties of the soils. As a permanent area, it is understood that the managements under study were always maintained on the same surface throughout the crop sequence. Each crop within the sequence depended on the conditions of the farms and the preferences of the farmers (Table 1).

Two treatments were evaluated: 1) traditional management of crops by farmers 2) traditional management plus the joint application of the AMF inoculant by seed coating at sowing or planting (15) and the application of sprayed chitosans with the recommended dose and time (16).

A quasi-experimental model (17) was used because the treatments were located in each of the farms in non-randomized plots, considering five samples in each plot as repetitions. Statistical processing was carried out by analyzing paired samples of each traditional management with the management of the bioproducts evaluated in each farm, by crop and year of sowing or planting, using the t-test (α = 0.05), to verify the hypothesis of the equality of the means between treatments, proposing as a null hypothesis that the samples are equal and as an alternative hypothesis that the samples differ from each other. All statistical analyses were performed using the STATGRAPHICS Centurion XVI statistical package (18).

Evaluations carried out

The determination of the agricultural yield (t ha^{-1}) was carried out by estimation based on the production volume. Two linear meters of different furrows located towards the center of the plots (19) were taken as the sampling area. Agricultural yields were determined by direct weighing of the harvest in the sampling area of each plot and subsequent extrapolation per unit area.

The economic analysis was carried out in Cuban pesos (CUP) and on the basis of the yields obtained in the crop sequences in the four permanent areas. The purchase price from farmers in the field that are marketed throughout the network, approved as of March 27, 2024 by the Provincial Government of Mayabeque (Table 2), was taken into account. The costs related to the application of the evaluated technology (AMF and chitosans) established by the INCA were also considered. The analysis did not take into account the different production costs involved (soil preparation, irrigation, cultural care, pest and disease control) as they were common to both treatments evaluated.

Table 2. Purchase price from farmers in the field

Description	Acquisition Price ($ t^{-1})
Sweet potato	33333.33
Squash	22222.22
Garlic	388888.89
Cucumber	33333.33
Tomato	77777.78
Pepper	77777.78
Dried corn	55555.56
Black bean	200000.00
Cassava	33333.33
Canavalia	33333.33

The methodology used was the proposal described in the UNAH Agricultural Economics Text (20) that assumes the evaluation of the following indicators:

- Production value ($ ha^{-1}) = yield (t ha^{-1}) × sale price ($ t^{-1})
- Total costs ($ ha^{-1}) = product cost ($ ha^{-1}) + product application cost ($ ha^{-1}) + harvest cost ($ ha^{-1}) + postharvest cost ($ ha^{-1})
    - Product cost ($ ha^{-1}) = product price ($ kg^{-1}) × dose (kg ha^{-1}) × number of applications (u)
    - Product application cost ($ ha^{-1}) = labor expenses ($ ha^{-1}) + material expenses ($ ha^{-1})
        - Labor expenses ($ ha^{-1}) = wage rate ($ h^{-1}) × man-hours (h)

    - Material expenses ($ ha^{-1}) = number of applications (u) × dose (kg ha^{-1}) × sale price ($ kg^{-1})
- Harvest cost ($ ha^{-1}) = labor expenses ($ ha^{-1}) + material expenses ($ ha^{-1})
    - Labor expenses ($ ha^{-1}) = wage rate ($ h^{-1}) × man-hours (h)
    - Material expenses ($ ha^{-1}) = number of applications (u) × dose (kg ha^{-1}) × sale price ($ kg^{-1})
- Postharvest cost ($ ha^{-1}) = 10% of the production value per hectare (yield × price)
    - Economic profit ($ ha^{-1}) = production value ($ ha^{-1}) - total costs ($ ha^{-1})
    - Benefit-cost ratio (B/C) = economic profit ($ ha^{-1}) ÷ total costs ($ ha^{-1})

In the research scenario, the payment of the working day of the agricultural workers linked to the production process was calculated at a rate of $80 h^{-1} ($400 per 5-hour day). The man-hours for the application of bioproducts, harvest, postharvest and benefits were estimated by crop and yield level based on the exchange with producers (Table 3).

The following equation was used to calculate the man-hours in the harvest of the plants with the management of the bioproducts, derived from the greater use of manpower due to increased yields:

$$Man - hours\ of\ harvest\ with\ bioproducts = Yield\ with\ bioproducts \div Yield\ with\ traditional\ management \times Man - hours\ of\ harvest\ with\ traditional\ management$$

RESULTS AND DISCUSSION

When analyzing the yields of the different crops in the permanent areas studied (Annex 1), it was observed that the treatments where the bioproducts were applied in all cases were superior to those of traditional management; except in the San Miguel farm, where no significant differences were found between the technologies evaluated for the beans planted in September 2018. It is possible that this result in the first crop of the sequence on the San Miguel farm is due to the fact that the area was previously covered with marabou (*Dichrostachys cinerea*) and at the beginning of the tests the soil had a high content of organic matter and nutrients.

In general, it is shown that the use of the AMF inoculant and the application of chitosans by foliar spraying had a positive effect on agricultural yield, as was found in the temporary areas where the validation studies were carried out in individual crops.

Similar results have been reported by other authors (21,22) when they state that once the plants make contact with the chitosans, signals are triggered that stimulate the defense mechanisms and collaterally produce a significant increase in the size of the root, its strengthening and vigor. Generally, these products are applied by foliar spraying and allow for the rapid correction of nutrient deficiencies at critical moments for crop development. However, other forms of application such as seed treatment by imbibition and addition to the substrate have been reported as positive in the biological benefit of crops.

Other studies agree that the joint application of both bioproducts enhances complementary mechanisms that improve nutrition, vigor, physiology, and the induction of defense mechanisms, among others (14,23). In such a way that they are no longer only applied independently to crops of economic interest, but rather, a way has been sought to combine their effects for better and greater plant growth and increased production.

The impact assessment using economic indicators enabled a comprehensive evaluation of the results obtained across four crop sequences. Treatments that showed the best performance in terms of yield and quality also demonstrated superior indicators of economic efficiency (Tables 4, 5, 6, and 7).

In this regard, the calculation of indicators revealed that the most effective management strategy was the combination of arbuscular mycorrhizal fungi (AMF) and chitosan-based biostimulants. Although this treatment involved higher monetary investment (production costs) due to the product dosages used, it achieved the highest production volume per hectare, resulting in greater production value and the best benefit/cost ratio compared to traditional management.

Table 3. Man-hours assigned to each crop to apply the AMF inoculant and chitosans and harvest the plants with traditional management

Activity	Applying AMF inoculant	Applying chitosans	Traditional Harvest and Management
Crop		**Hours/men**	
Garlic	2	8	100
Sweet potato	20	8	32
Squash	1	3	40
Canavalia	2	8	20
Beans	2	8	20
Maize	2	8	20
Cucumber	10	8	20
Pepper	10	8	20
Tomato	10	8	20
Cassava	8	8	40
Cassava/canavalia	10	8	60

Data Based on Interviews with Farmers

Table 4. Economic Analysis of La Chivería Farm

Indicators	Treatments	Crop Sequence												
		Bean	Pepper	Cassava	Garlic	Maize	Bean	Tomato	Maize	Bean	Garlic	Canav.	Tomato	Bean
Production value (M$ ha^{-1})	AMF + Chitosans	78.84	1131.64	798.29	434.80	196.38	156.53	2167.55	115.95	156.53	426.10	29.61	1914.93	156.53
	Traditional management	54.49	580.46	450.13	221.75	74.28	89.86	1339.18	64.31	81.16	198.27	18.59	1265.63	78.26
Production cost (M$ ha^{-1})	AMF + Chitosans	12.92	47.17	26.83	24.10	26.63	20.69	18.39	17.38	19.89	24.70	17.00	20.15	24.69
	Traditional management	9.45	28.80	16.00	15.89	10.43	11.99	14.40	10.76	10.52	13.10	7.86	18.00	14.83
Economic Benefit (M$ ha^{-1})	AMF + Chitosans	65.92	1084.48	771.47	410.70	169.76	135.84	2149.16	98.56	136.64	401.40	12.61	1894.78	131.84
	Traditional management	45.05	551.66	434.13	205.86	63.85	77.87	1324.78	53.55	70.65	185.17	10.73	1247.63	63.44

Canav.: canavalia

Table 5. Economic Analysis of El Mulato Farm

Indicators	Treatments	Crop Sequence											
		Maize	Bean	Cassava	Bean	Maize	Cucumber	Bean	Maize	Tomato	Bean	Maize	bean
Production value (M$ ha^{-1})	AMF + Chitosans	211.06	387.26	671.55	347.84	221.02	1489.33	244.65	186.96	6803.75	284.07	174.10	179.72
	Traditional management	128.63	167.54	303.16	173.92	163.05	746.44	86.38	115.95	3678.98	121.74	123.56	130.44
Production cost (M$ ha^{-1})	AMF + Chitosans	29.38	50.60	19.84	50.58	33.65	24.95	38.16	27.91	697.17	40.04	26.29	29.03
	Traditional management	19.09	22.75	12.00	26.99	24.66	14.00	17.87	18.04	377.50	21.40	18.95	21.60
Economic Benefit (M$ ha^{-1})	AMF + Chitosans	181.68	336.66	651.71	297.26	187.37	1464.38	206.49	159.05	6106.58	244.03	147.81	150.69
	Traditional management	109.54	144.79	291.16	146.93	138.40	732.44	68.51	97.90	3301.48	100.34	104.61	108.84

Table 6. Economic Analysis of San Miguel Farm

Indicators	Treatments	Crop Sequence												
		Bean	Cassava/ Canav.	Maize	Sweet potato	Canav.	Garlic	Maize	Sweet potato	Bean	Sweet potato	Tomato	Sweet potato	Maize
Production value (M$ ha^{-1})	AMF + Chitosans	69.86	1123.52	211.97	610.13	170.03	3391.44	192.04	407.63	76.52	407.63	160.04	485.89	70.66
	Traditional management	61.10	902.64	126.82	405.99	97.83	1782.68	121.38	284.79	46.38	284.79	74.57	350.56	18.12
Production cost (M$ ha^{-1})	AMF + Chitosans	10.85	14.93	24.36	15.39	23.64	55.94	23.37	9.39	13.19	11.39	11.62	11.00	14.05
	Traditional management	9.97	12.60	17.28	12.00	15.18	38.00	17.26	8.00	8.41	8.12	10.03	8.00	7.81
Economic Benefit (M$ ha^{-1})	AMF + chitosans	59.01	1108.59	187.61	594.74	146.39	3335.50	168.67	398.24	63.34	396.24	148.42	474.89	56.60
	Traditional management	51.13	890.04	109.54	393.99	82.65	1744.68	104.12	276.79	37.97	276.67	64.54	342.56	10.30

Canav.: canavalia

These findings align with those reported in related studies on new natural products for agriculture, which demonstrated economic feasibility in productive management. Both bioproducts provided superior economic benefits compared to traditional practices, as they promoted increased yields (24). The application of bioproducts in agriculturally relevant crops has proven effective due to their ability to enhance nutrient and water absorption, resistance to biotic and abiotic stresses, and the production of active substances involved in plant growth and development (25).

Furthermore, these results are consistent with findings from other studies (26-28) on the economic effects of using domestically produced bioproducts. Their implementation-whether complemented by mineral fertilizers or organic amendments-has shown positive outcomes across a wide range of crops, including sweet potato, maize, plantains, pasture grasses, tobacco, and beans. In some cases, inoculated legumes were used as green manure preceding various crops, consistently ensuring high yields comparable to those obtained with the full recommended dose of mineral fertilization. This behavior demonstrates that efficient nutrient utilization through bioproducts brings benefits to production, the environment, and directly impacts farmers' economic outcomes. Poor utilization of invested resources in crop growth and development leads to economic losses for farmers.

Table 7. Economic Analysis of Santa Catalina Farm

Indicators	Treatments	Crop Sequence														
		Bean	Maize	Sweet potato	Maize	Bean	Maize	F	Bean	Maize	Can.	Squ	Maize	F	Beans	Tomato
Production value (M$ ha^{-1})	AMF + Chitosans	320.01	192.22	348.38	202.00	217.40	165.77		104.35	183.70	20.09	235.52	67.94		149.57	1873.08
	Traditional management	187.83	123.19	277.29	109.06	139.14	119.93		60.87	106.35	15.65	162.33	46.20		43.48	1461.94
Production cost (M$ ha^{-1})	AMF + Chitosans	40.48	27.17	21.39	29.20	28.82	23.56		16.79	25.12	8.84	37.45	26.61		16.36	202.58
	Traditional management	24.78	18.32	20.00	16.82	19.16	17.24		10.09	15.43	7.17	27.03	18.32		7.05	158.34
Economic Benefit (M$ ha^{-1})	AMF + Chitosans	279.54	165.05	326.99	172.80	188.59	142.20		87.56	158.59	11.24	198.06	41.33		133.22	1670.50
	Traditional management	163.05	104.87	257.29	92.24	119.97	102.69		50.78	90.91	8.49	135.29	27.88		36.43	1303.60

F: fallow (land left to rest for at least three months); Can.: canavalia; Squ.: squash

Similar results were revealed in studies on the feasibility and economic impact of joint bioproduct application under farm production conditions. These studies agree that the effectiveness depends on the crop's response level, directly reflected in the yields obtained, which may vary depending on the soil and climate conditions of the production area, the time of year, or the characteristics of the agricultural season (30).

Meanwhile, other authors (29) argue that improper plant nutrition management, resulting in nutrient losses, is the main factor interfering with productivity and increasing crop production costs-a common issue in many tropical agricultural ecosystems.

Sustained economic growth drives progress, creates employment opportunities, and improves living standards. In the case at hand, a significant impact was achieved in the economic dimension due to the increased value of food production. This led to higher profits and resulted in a favorable benefit-cost ratio (Annexes 2, 3, 4, and 5).

These outcomes are attributed to the synergistic effect of bioproducts based on arbuscular mycorrhizal fungi (AMF) and chitosan on crop growth and development within agricultural systems. Their proper adoption enabled crop diversification and rotation in sequences, contributing substantially to the economic independence of farmers (Table 8).

It is also agreed that these practices help lay the foundation for domestic-scale food sovereignty, as affirmed by several authors in previous studies (31).

In general, due to the multidisciplinary impact it generates across various sectors of the country, the use of this technology in other crops is both decisive and strategic. Agricultural production, as Cuba's primary economic activity, demands the implementation of sustainable farming systems.

CONCLUSIONS

The combined application of inoculants and chitosan-based bioproducts significantly enhances agricultural yields in crop sequences developed under real production conditions on diversified farms, demonstrating their effectiveness as a strategy to improve both productivity and sustainability in farming systems.

Impact assessment using economic indicators revealed that the implementation of bioproduct-based technology led to increases in production value and profits, as well as an improved benefit/cost ratio compared to traditional management practices-despite the rise in production costs.

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Table 8. Economic impact of the innovation adopted in the four production systems

Economic Indicators	La Chivería	El Mulato	San Miguel	Santa Catalina
Production value	3	3	3	3
Increase in production value	3	3	3	3
Production costs	2	2	2	2
Economic benefits	3	3	3	3
Benefit/Cost ratio (B/C)	3	3	3	3

(1) No impact or less than 25 %; (2) Impact between 25 % and 75 %; (3) Impact greater than 75 %

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Annex 1. Yields (t ha⁻¹) obtained from the crop sequences carried out on the four farms under study

Crop Sequence	Planting Date	AMF + Chitosan	Traditional Management	Confidence Interval	Crop Sequence	Planting Date	AMF + Chitosan	Traditional Management	Confidence Interval
		La Chivería					El Mulato		
Beans	sep-2017	0.45	0.31	± 0.04	Maize	jun-2017	3.88	2.37	± 0.31
Pepper	dec-2017	26.03	13.35	± 2.81	Beans	oct-2017	2.23	0.96	± 0.07
Cassava	mar-2018	24.48	13.8	± 2.29	Cassava	feb-2018	20.59	9.30	± 0.95
Garlic	nov-2018	1.67	0.85	± 0.26	Beans	dec-2018	2.00	1.00	± 0.18
Maize	apr-2019	3.61	1.37	± 0.30	Maize	apr-2019	4.07	3.00	± 0.39
Bean	sep-2019	0.9	0.52	± 0.12	Cucumber	sep-2019	19.57	9.81	± 0.84
Tomato	jan-2020	28.49	17.6	± 2.17	Bean	jan-2020	1.41	0.50	± 0.11
Maize	jun-2020	2.13	1.18	± 0.29	Maize	may-2020	3.44	2.13	± 0.14
Beans	sep-2020	0.9	0.47	± 0.19	Tomato	sep-2020	39.12	21.15	± 1.16
Garlic	dec-2020	1.63	0.76	± 0.13	Bean	jan-2021	1.63	0.70	± 0.26
Canavalia	apr-2021	1.51	0.95	± 0.11	Maize	jun-2021	3.20	2.27	± 0.24
Tomato	aug-2021	25.17	16.63	± 1.79	Bean	mar-2022	1.03	0.75	± 0.06
Bean	dec-2021	0.9	0.45	± 0.09					

±: confidence interval of the means (α = 0.05)

Annex 1. Yields (t ha⁻¹) obtained from the crop sequences carried out on the four farms under study (continued)

Crop sequence	Planting Date	AMF + Chitosan	Traditional Management	Confidence Interval	Crop sequence	Planting Date	AMF + Chitosan	Traditional Management	Confidence Interval
		San Miguel					Santa Catalina		
Bean	sep-2018	0.40	0.35	± 0.26	Bean	nov-2017	1.84	1.08	± 0.23
Cassava/ canavalia	jan-2019	21.53	17.30	± 1.31	Maize	apr-2018	3.54	2.27	± 0.14
Maize	nov-2019	3.90	2.33	± 0.19	Sweet potato	sep-2018	10.68	8.50	± 1.03
Sweet potato	apr-2019	18.71	12.45	± 2.18	Maize	feb-2019	3.72	2.01	± 0.29
Canavalia	aug-2020	8.69	5.00	± 1.84	Bean	sep-2019	1.25	0.80	± 0.19
Garlic	nov-2020	13.00	6.83	± 1.62	Maize	jan -2020	3.05	2.21	± 0.16
Maize	apr-2021	3.53	2.23	± 0.24	Fallow	jun-2020			
Sweet potato	jul-2021	12.50	8.73	± 0.15	Bean	sep-2020	0.60	0.35	± 0.09
Bean	nov-2021	0.44	0.27	± 0.04	Maize	jan -2021	3.38	1.96	± 0.14
Sweet potato	feb-2022	12.50	8.73	± 0.15	Squash	apr-2021	1.03	0.80	± 0.10
Tomato	sep-2022	2.10	0.98	± 0.14	Calabaza	sep-2021	10.83	7.47	± 0.35
Sweet potato	jan-2023	14.90	10.75	± 0.35	Maize	jan -2022	1.25	0.85	± 0.06
Maize	feb-2023	1.30	0.93	± 0.14	Fallow	jun-2022			
					Bean	sep-2022	0.86	0.25	± 0.04
					Tomato	nov-2022	24.62	19.21	± 1.25

±: confidence interval of the means (α = 0.05)

Annex 2. Increase in the Benefit/Cost ratio and yield increments by crop type at La Chivería Farm

Treatments	Bean	Pepper	Cassava	Garlic	Maize	Bean	Tomato	Maize	Bean	Garlic	Canavalia	Tomato	Bean
AMF + Chitosan	5.10	22.99	28.76	17.04	6.38	6.56	116.85	5.67	6.87	16.25	0.74	94.02	5.34
Traditional Management	4.77	19.15	27.13	12.96	6.12	6.50	92.00	4.98	6.72	14.14	1.37	69.31	4.28
Increase in the Benefit/ Cost ratio	1.07	1.20	1.06	1.31	1.04	1.01	1.27	1.14	1.02	1.15	0.54	1.36	1.25

Annex 3. Increase in the Benefit/Cost ratio and yield increments by crop type at El mulato Farm

Treatments	Maize	Bean	Cassava	Bean	Maize	Cucumber	Bean	Maize	Tomato	Bean	Maize	Bean
AMF + Chitosan	6.18	6.65	32.86	5.88	5.57	58.69	5.41	5.70	8.76	6.09	5.62	5.19
Traditional Management	5.74	6.36	24.26	5.44	5.61	52.32	3.83	5.43	8.75	4.69	5.52	5.04
Increase in the Benefit/Cost ratio	1.08	1.05	1.35	1.08	0.99	1.12	1.41	1.05	1.00	1.30	1.02	1.03

Annex 4. Increase in the Benefit/Cost ratio and yield increments by crop type at San Miguel Farm

Treatments	Bean	Cassava/ Canav.	Maize	Sweet potato	Canavalia	Garlic	Maize	Sweet potato	Bean	Sweet potato	Tomato	Sweet potato	Maize
AMF + Chitosan	5.44	74.25	7.70	38.64	6.19	59.63	7.22	42.41	4.80	34.79	12.77	43.17	4.03
Traditional Management	5.13	70.64	6.34	32.83	5.44	45.91	6.03	34.60	4.51	34.07	6.43	42.82	1.32
Increase in the Benefit/Cost ratio	1.06	1.05	1.21	1.18	1.14	1.30	1.20	1.23	1.06	1.02	1.99	1.01	3.05

Annex 5. Increase in the Benefit/Cost ratio and yield increments by crop type at Santa Catalina Farm

Treatments	Bean	Maize	Sweet potato	Maize	Bean	Maize	F	Bean	Maize	Canavalia	Squash	Maize	F	Bean	Tomato
AMF + Chitosan	6.91	6.07	15.29	5.92	6.54	6.03		5.22	6.31	1.27	5.29	1.55		8.15	8.25
Traditional Management	6.58	5.72	12.86	5.48	6.26	5.96		5.03	5.89	1.18	5.00	1.52		5.17	8.23
Increase in the Benefit/Cost ratio	1.05	1.06	1.19	1.08	1.04	1.01		1.04	1.07	1.08	1.06	1.02		1.58	1.00