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Economic and Productive Impact of the Implementation and Use of Agricultural Irrigation in the State of Tabasco, Mexico

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ABSTRACT

Objective: Three support programs for agricultural irrigation in 8 municipalities in the State of Tabasco were evaluated for a total area of 972.4 ha with 7 crops per municipality. One production cycle was used for the evaluation of the irrigation units in the State of Tabasco.

Design/methodology/approach: The software "System for the Evaluation of Irrigation Units" SISEVUR 3.0 was used for the integration and evaluation of a) general operation of infrastructure; b) producer satisfaction with the infrastructure; c) aspects of improvement in the quantity and quality of production; d) benefits of irrigation on agricultural production and suggestions and opinions of producers regarding hydro-agricultural programs e). The economic/financial evaluation.

Results: The crops that responded best to the application of irrigation were: 1) forage corn, with an increase in production of 140.7%; 2) lemon with 97.98%; 3. banana with 58.6%, and 4 sugar cane with 41%.

Limitations on study/implications: Data collection required several visits to the producer to improve the collection of reliable data. However, there is a margin of error that could not be quantified due to the particularities of the producers and the work.

Findings/conclusions: Bananas and citrus improved production quality and product maintenance throughout the year, favoring supply and demand commitments in the domestic and international markets.

Keywords: irrigation, water efficiency, evapotranspiration, agricultural productivity.

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INTRODUCTION

The State of Tabasco, in Mexico, experiences abundant rainfall with an average of 2,543.8 mm*year^{-1} (Agenda Técnica Agrícola Tabasco, 2015). Although these rains might suggest that water needs for crops are satisfied, the temporal distribution is not optimal for ideal agricultural development despite being one of the wettest regions in the country (CONAGUA, 2014). Excess moisture is observed between June and December, while water deficits occur from February to May, negatively impacting production. Consequently, an increasing number of farmers are turning to irrigation systems as a solution (Mendoza-Hernández *et al.*, 2021).

State of Tabasco ranks first in terms of surface water resources availability in the country, as the Usumacinta and Grijalva rivers, which run through the region, transport more than 116 billion m^3*year^{-1} (Velázquez, 1994). However, this water resource does not fully benefit agricultural activity in Tabasco, which occupies an area of 223,089 hectares, composed of 111,574 ha of perennial crops and 111,515 ha of annual crops, the majority of which rely on rainfall (INEGI, 2017). Currently, only 3% of this agricultural land is equipped with irrigation systems, which approximately amounts to 6,692 ha (SEDAFOP, 2023).

Rainfall in State of Tabasco does not exhibit a homogeneous distribution throughout the year. During the dry season, precipitation falls below 100 mm/month, leading to a water deficit (Bamber *et al.*, 2012) that reduces productivity, especially in sensitive crops such as bananas (Martínez-Varona, 2013). To ensure optimal moisture conditions, the use of supplementary irrigation becomes indispensable. This plays a fundamental role in plantation management, contributing to maintaining fruit quality and productivity throughout the year (Castillo, 2005). Additionally, it has enabled farmers to venture into international markets (Cigales & Pérez, 2011).

With the aim of economically evaluating and financially assessing the Federal Government programs related to irrigation, this study utilized the 'Irrigation Units Evaluation System' (SISEVUR 3.0), provided by CONAGUA. These economic evaluations and financial assessments are essential for examining the efficiency, effectiveness, quality, and social impact of agricultural investment projects, in accordance with Article 26 of the Federal Expenditure Budget in Mexico.

MATERIALS AND METHODS

The irrigation programs assessed in this study were the Efficient Use of Water and Electric Energy Program (UEAEE-2008), the Full Use of Hydroagricultural Infrastructure Program (UPIH-2008), and the Modernization and Technification of Irrigation Units Program (MOTUR 2011 and 2012), which are federal government programs supported by the Ministry of Energy (2015) and CONAGUA (2014) (Mexican Official Standard NOM-006-2015). These programs were economically and financially evaluated using the 'Irrigation Units Evaluation System' (SISEVUR 3.0).

The study was conducted in eight municipalities in the State of Tabasco, selected based on their importance in terms of the number of irrigation works. The evaluated municipalities were Huimanguillo with 10 works (433.4 ha), Cárdenas with eight (211 ha), Teapa with six (149 ha), Balancán with two (90 ha), Cunduacán with two (43 ha), and the municipality of Centro with one (16 ha). A total of 29 irrigation works were evaluated out of a total of 31. The benefited crops, in order of importance according to the number of hectares, were sugarcane (*Saccharum officinarum* L.) with 253 ha, forage and grain maize (*Zea mays* L.) with 236.4 ha, lemon (*Citrus limon* (L.) Osbeck) with 220 ha, banana (*Musa paradisiaca* L.) with 175 ha, cut forage grass (*Panicum maximum* Jacq.) with 48 ha, pineapple (*Ananas comosus* (L.) Merr.) with 30 ha, and vegetables with 10 ha. In total, an area of 972.4 ha was evaluated.

The analysis of the irrigation program data (UPIH, UEAEE, and MOTUR for the years 2011 and 2012) was conducted in two stages: a desk stage and a field stage. The desk stage involved reviewing the 31 technical files containing information regarding: general data of the beneficiary producers, plot data (surface area and crop), type of hydroagricultural work performed (type of irrigation system installed), data on hydraulic utilization, concessioned volume, and data on the percentages of economic participation for the works of the state and federal governments, as well as the beneficiary producer. This information was recorded in an Excel spreadsheet for subsequent analysis.

The field stage consisted of verifying the condition of the installed irrigation infrastructure, general functioning of the irrigation system, crops benefited by irrigation, crop production data, depth of irrigation requirements, hydraulic expenditure, pumping hours, volume of water used, gross and net irrigation depth applied, irrigation efficiency, planted and harvested area, production value, and, importantly, beneficiary producers were asked about the attention received from government agencies to obtain support and their satisfaction upon completion and delivery of the irrigation work. Field information was obtained through the application of a structured questionnaire in three sections: a) characterization of the beneficiary producer; b) technical and operational data of the irrigation work; and c) production (harvested tons and selling price). All information was captured in the computer program 'Irrigation Units Evaluation System' (SISEVUR 3.0). With the collected data, the following indicators were calculated: 1) Gross Land Production (GLP) before and after irrigation, 2) Net Land Production (NLP) before and after irrigation, 3) Gross and net water production after irrigation, 4) Economic water efficiency, and 5) Water applied vs production ratio. The main objective was to determine the incremental difference in agricultural production due to irrigation use. To evaluate the production value at real prices in the 'after' scenario of irrigation use, the production value obtained 'before' irrigation use was updated using the monthly inflation rate issued by INEGI in Mexico. In the study, the Cost-Benefit Analysis method was used to evaluate the financial viability of irrigation programs. This method is based on quantifying benefits and costs in monetary terms, although in practice it is not always possible to quantify all benefits and costs accurately (Dupuit, 1844). To compare the values of gross (GLP) and net land productivity (NLP) before and after irrigation for sugarcane (CA), forage maize (MF), citrus (C), and banana (P), the Student's t-test for the mean of two paired samples was used with a significance level of 5% (alpha=0.05).

RESULTS AND DISCUSSION

The total investment in the 31 projects amounted to 35.17 million pesos (mp). The contribution from the three sectors (federal government, state government, and beneficiary producers) was as follows: the National Water Commission contributed 14.27 mp, the government of the State of Tabasco contributed 11.59 mp, and the beneficiary users contributed 9.31 mp.

The majority of the beneficiaries of these supports had a favorable opinion regarding the degree of satisfaction with the results of the programs (maximum=23/27), and regarding the management time of a project (fast=26/28), that is, from the initiation of procedures until the achievement of resources and signing of the commitment letter through the publication of results, as well as the opportunity of the available economic resources (excellent=22/27): which indicates that the programs are well-founded, have all the necessary elements for their operation, have clear rules, as well as well-established timelines, and the availability of resources was in a timely manner.

The opinions and suggestions of the beneficiaries agreed on the need for every farmer with irrigation works to be provided with a Training Course in irrigation management, to

be offered technical assistance, and for the irrigation programs to be continued. They also expressed the need to simplify procedures to access financial support and to make them accessible to small landowners. This aligns with Aguillón's recommendations (2020) on the importance of providing training and technical assistance to producers for adequate irrigation management, as well as simplifying procedures to facilitate access to support, especially for small farmers.

An essential aspect was their opinion, when they stated that these programs have allowed them to improve productivity and the quality of production (70%), and that the above allows them to ensure production (30%). Pérez-Magaña *et al.* (2019) found that local agricultural practices such as crop diversification and water reuse also contribute to ensuring production, which could complement the strategies of producers in the State of Tabasco.

It was also observed that the volumes granted by CONAGUA were much higher than those used by the farmer, which meant that the use of water was lower than initially estimated and that the water was being used appropriately (Figure 1). Palacios-Vélez and Escobar-Villagrán (2016) mention that it is necessary to promote a culture of payment for water service and reduce subsidies to encourage more efficient management of the resource, which could be relevant considering the low use of water volumes concessioned in the State of Tabasco.

To carry out the financial evaluation of irrigation programs, it is necessary to assess the amount of the investment, as aforementioned. Figures 2 and 3 compare the Gross Land Productivity (GLP) and the Net Land Productivity (NLP), respectively, comparing before and after irrigation. It can be seen that for both productivity the increases of the "after" profits are consistent for the crops (SC) Sugarcane; (FM) Forage maize; (C) Citrus fruits and (B) Banana.

Nevertheless, profits are higher in banana and citrus cultivation, since, according to producers, the use of irrigation resulted in larger fruits, particularly in the case of lime. This statement is corroborated by the findings of Medellín-Azuara *et al.* (2010). Consequently, it is concluded that irrigation serves as an excellent catalyst for banana cultivation or that the crop responds favorably to the application of irrigation.

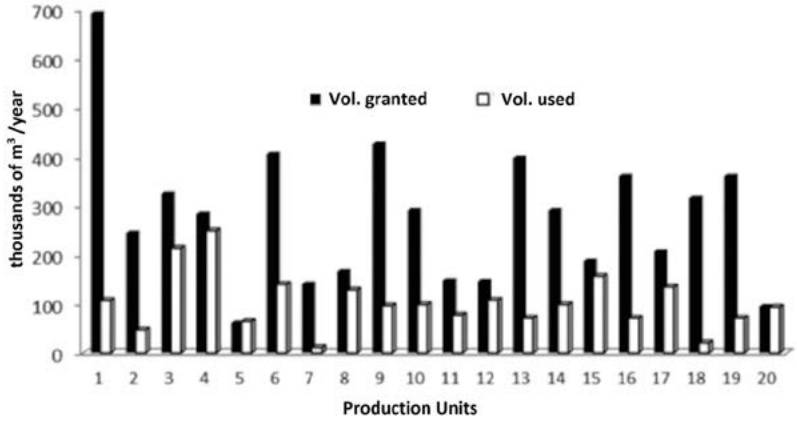

Figure 1. Behavior of water volumes granted *vs.* used.

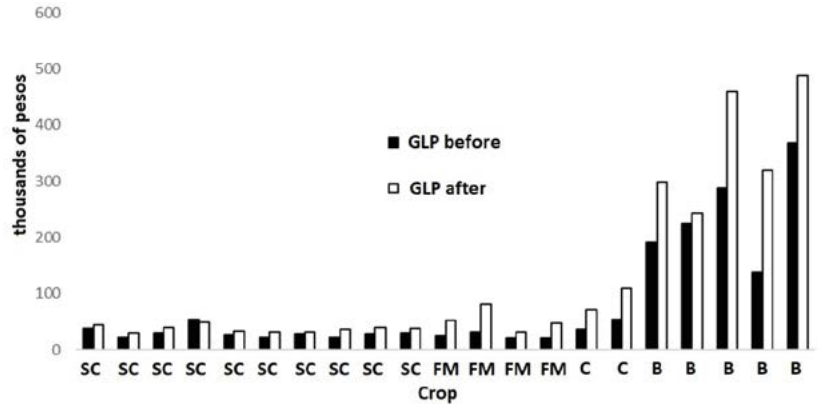

Figure 2. Gross Land Productivity in thousands of pesos (GLP), before and after irrigation, for sugarcane (SC); forage maize (FM), citrus (C) and banana (B).

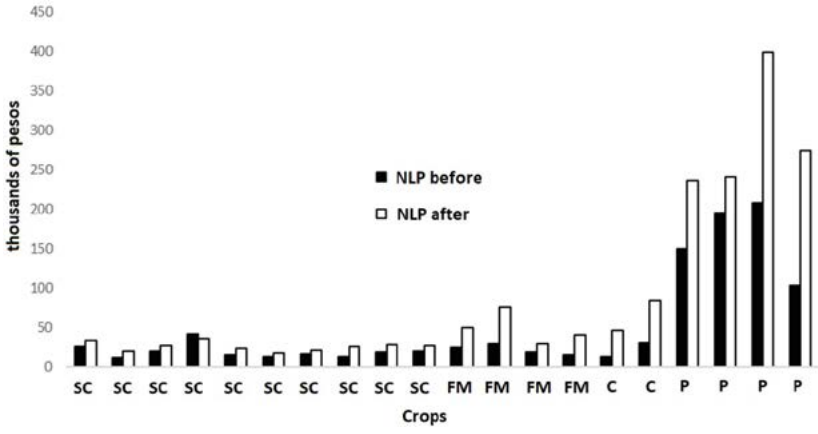

Figure 3. Net Land Productivity in thousands of pesos (NLP), before and after irrigation, for sugarcane (SC), forage maize (FM), citrus (C), and banana (B).

This production behavior is consistent with that reported by Colimba *et al.* (2021). The methodological approach and productivity and economic efficiency indicators developed by Villalobos-Cano *et al.* (2020) could be useful for further analyzing the impact of irrigation on the productivity and profitability of different crops in the State of Tabasco.

The aforementioned is confirmed by applying a Student's t-test, where significant differences were observed in the earnings before and after the application of irrigation (Table 1). These results for banana and lime trees can be attributed to the experience in irrigation management that producers of these crops already have in the region, as mentioned by Santacruz and Santacruz (2020). Irrigation management is a central factor that ensures applied water reaches the soil and plants, resulting in a favorable crop response. Hence, the importance of subjecting different irrigation methods to constant hydraulic evaluation. For the other crops, there were no significant differences, but this does not imply that they do not respond to irrigation, but possibly due to the limited experience of the producers, who had never used irrigation before (Table 1). Pérez-Magaña *et al.* (2019) emphasize the importance of social organization and customary rules among producers

Table 1. T-test for means of two paired samples. Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) of land in banana cultivation.

	GPP		NPP	
	Variable 1	**Variable 2**	**Variable 1**	**Variable 2**
Mean	242	362	164	288
Variance	7962	11347	2288	5787
Observations	5	5	4	4
CCP	0.791		0.452	
DHM	0		0	
Degrees of freedom	4		3	
t Statistic	−4.100		−3.568	
P(T≤t) one-tail	0.00743		0.019	
t Critical one-tail	2.132		2.353	
P(T≤t) two-tail	0.0149		0.038	
t Critical two-tail	2.776		0.038	

CCP: Coeficiente de correlación de Pearson, DHM: Diferencia hipotética de la media.

for collective water management and irrigation infrastructure, which could be relevant for strengthening the adoption and proper management of irrigation systems in the State of Tabasco.

From the field data collected regarding the production of crops benefited by irrigation, it can be seen in Table 2 that the average production values increased for all crops. When the Student's t-test was evaluated, a value of $p \leq 0.05$ was obtained, so it was concluded that there were noteworthy differences between crop yields before and after irrigation.

It is worth mentioning that in addition to the increases recorded in production volumes (Table 3), the quality of production was also improved (Medellín-Azuara *et al.*, 2010). As mentioned, (Yedra *et al.*, 2016), irrigation is an auxiliary factor in production, which favors the plant and fruit vegetative development; and ensures quality in agricultural products, especially for export markets.

In this study, this could be confirmed, especially in the case of banana and lime trees, which allowed producers to increase their participation in the international market. As mentioned by Vidal *et al.* (2021) and Castelán-Estrada *et al.* (2021), banana is considered in State of Tabasco as one of the main drivers of the region's economy, since around half a million boxes are exported monthly to the United States, Asia, Europe, and Russia,

Table 2. Average value of gross land production (AVGLP) and Average value of net land production (AVNLP), in thousands of pesos per year.

Crop	Before irrigation		After irrigation	
	AVGLP	**AVNLP**	**VPPBT**	**VPPNT**
Sugarcane	30.4	37.5	19.5	25.7
Forraje maiz	24.8	52.8	21.6	65.5
Citrus	45.7	90.6	21.2	65.5
Banana	242.4	362.2	164.2	287.7

mainly. Furthermore, this allowed ensuring production volumes, a fundamental aspect in the international market. The quality of production could be determined considering the export volumes that were reported, in the case of lime trees up to 15%, and in the case of bananas up to 27.5% of the total production (data retrieved from producers).

The production costs of crops, ordered from lowest to highest investment in crop establishment are as follows: forage grass ($15,000*ha^{-1}), secondly, forage maize ($35,000*ha^{-1}), followed by bananas ($52,000*ha^{-1}), and finally, pineapples ($150,000*ha^{-1}). The production costs with irrigation increased on average by 38%; however, the profits also increased. For example, gross land productivity (GLP) increased by 60%, and net land productivity increased by 87%.

The authors Palacios-Vélez and Escobar-Villagrán (2016) address important topics such as the challenges of aquifer overexploitation, the methods to evaluate it, and management recommendations, in addition to techniques to update well censuses, the establishment of technical committees, and implementing artificial recharge projects. These aspects were not considered in this study; however, they are relevant for a more sustainable management of water sources used for irrigation. Other aspects to be delved into in similar studies, according to Ibarra Aguillón (2020), include public investment in irrigation programs, requested irrigation systems, and water savings achieved, which could complement the financial and water impact analysis of the evaluated programs.

Based on the information obtained regarding the economic and productive impact of agricultural irrigation in the State of Tabasco, several implications, solutions, and proposals can be identified that could be considered by government agencies in the state in order to improve and maximize the benefits of irrigation in agriculture.

Firstly, the study clearly demonstrates that the implementation of irrigation systems has had a significant impact on increasing the productivity and quality of crops, especially in the case of bananas, citrus fruits and sugar cane. This implies that the State government should continue investing in agricultural irrigation support programs and expanding their coverage to benefit more farmers. It is crucial to simplify procedures and processes so that small-scale farmers can easily access financial support.

Furthermore, the study also points out the importance of providing training and technical assistance to farmers in proper irrigation management. Therefore, it is suggested that the government of the State of Tabasco strengthen agricultural extension programs and provide specific training courses on efficient irrigation techniques and water management. This would help farmers optimize the use of water resources and maximize the benefits of their irrigation systems.

Table 3. Increases in crop production with the irrigation use.

Crop	Without irrigation	With irrigation	Increase %
	Tons/ha		
Forage Maize	27.0	65.0	140.7
Lemon	24.5	48.5	58.5
Sugarcane	61.7	87.0	41.0
Pineapple	80.0	110.0	37.5

Although the issue of insecurity has not been addressed in the article, some consulted farmers mentioned insecurity and the theft of irrigation equipment. It is essential for the State government to implement security measures and surveillance in agricultural areas where these systems have been installed. This could include collaboration with local authorities and the community to establish protection and reporting mechanisms against criminal acts that affect farmers.

Finally, considering the potential of banana and citrus crops to access international markets thanks to irrigation, it is recommended that the government promote association between farmers, research centers and entrepreneurs, and also provide support in marketing and exportation of these products.

The study on the impact of agricultural irrigation in the State of Tabasco offers valuable lessons and opportunities for the state government to take concrete actions for the benefit of farmers and rural development. Through continuous investment in irrigation programs, technical training, simplification of procedures, field security, and support in marketing, the State of Tabasco can maximize the potential of its agriculture and improve the quality of life of its producers.

CONCLUSIONS

The use of irrigation technology has represented a significant advancement in agriculture, increasing crop production and quality, which in turn has allowed continuous production and facilitated access to international markets. A 42% increase in sugarcane production was reported after adopting irrigation systems, accompanied by a notable increase in net productivity, reaching in some cases more than 70%. This advance translates into an increase in income and profitability, especially in crops such as bananas, which have managed to penetrate international markets and obtain higher prices. The economic benefits obtained motivate farmers to invest in advanced technology, which improves their quality of life. However, they face challenges such as insecurity, highlighting the need for irrigation training for more efficient management of water and economic resources, and to mitigate security problems.

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