ISBN: 978-628-96613-3-0. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2026.1.1.113

Rice as a staple food in Panama

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Abstract*– The article shows nonlinear regressions of five cases of the agricultural sector in Panama, specifically the hectares of sowing are related to the harvest in quintals. The correlation and determination coefficients are determined for each of the five cases and in each case the period with greater efficiency is estimated, that is, the one with the greatest number of quintals harvested in a smaller planting area as a measure of productivity. An analysis and discussion of the results is carried out and the conclusions are presented.

Keywords-- Rice, Panama, nonlinear regression, agriculture, food

I. INTRODUCTION

The agricultural sector corresponds to the primary sector of the economy. It is made up of the agricultural sector and the livestock sector. Because it is so broad, it has a strategic importance in the economic and social development of Panama due to its participation in the GDP, its impact on the living conditions of the rural population, and its importance as a provider of food and supplies for the rest of the population, for industry and the tourism sector, the last being of great importance. To guarantee food security and inputs to the industry, agricultural productivity must be considerably increased; to this end, it is necessary to address these aspects from the perspective of research, technological development and innovation, production processes to ensure the quality and safety of food, sanitary and phytosanitary management of agricultural production, the use of by-products of said productions, diversification and new uses of products, the development of innovative, functional products, energy crops, scientific evidence to support sanitary and phytosanitary measures for domestic and foreign trade, quality standards, harvest and post-harvest processes, logistics and marketing and handling processes, the improvement of supply chains, knowledge management processes for technical change, among other aspects [1].

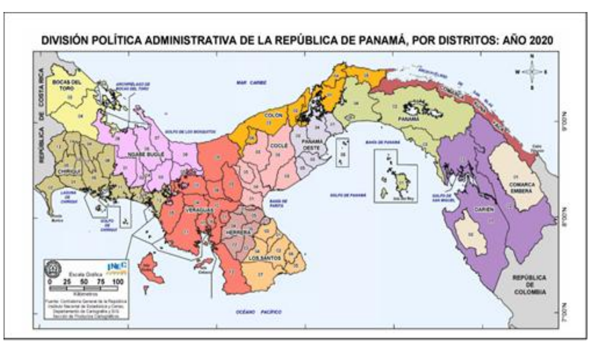

Figure 1. Map of Republic of Panama[2]

This article presents regression analysis of the Panamanian statistics rice production, specifically in the provinces of Chiriquí, Veraguas, Panama, Coclé and the country (See figure 1). Rice is the most important cereal in the developing world; it is the basic food for most of the planet's population. In the countries of South America and the Caribbean it is the main energy source for the low-income population. In intensive rice production, the soil is subjected to excessive preparation that causes the loss of its structure, increases erosion, the formation of compacted layers, leads to a decrease in porosity, the infiltration rate and reduces its natural fertility, decreasing its productivity and producer income [3]. In Panama, 6 million quintals of rice are grown per year on an area of land of approximately 62 thousand hectares [4]. Panama is one of the countries that has the highest per capita consumption of rice in Central America. According to studies carried out by INCAP, 9 out of 10 Panamanians consume rice daily. It represents the most consumed food in the category of cereals and derivatives, with a national average of 158 g/day [5].

II. BRIEF BACKGROUND AND CONTEXT

Rice cultivation has its own life cycle. The vegetative and reproductive cycle of the new cultivated rice varieties varies between 100-120 days, from germination to grain harvest. When temperatures are low during the vegetative cycle, it is extended for a few more days, according to information from IDIAP, although these times depend on the varieties of rice that are planted and whether it was early, intermediate or late. When grown under rainfed conditions, between 1,000 mm and 4,000 mm per year are required. They are planted in moist, flooded soil. Good yields occur with 200-300 mm of well-distributed rain per month. The most critical stage is the 10 days before flowering [6]. In general, several studies have been carried out on the production of Panamanian rice taking into account aspects such as genetics, soil quality [7], [8], rainfall levels, cultivation method [9], pest control[10]among other aspects[11], [12], [13], [14], [15], [16], [17]. Barahona *et al.,* [11] carried out a study about the absorption of nutrients from the cultivation of two varieties of rice in the province of Los Santos. Zambrano-Vega *et al.,* [12] determined the favorable areas for rice cultivation in Panama. Camargo-Buitrago *et al.,* [13] conducted a study where they provided a series of key recommendations to improve rice planting. These recommendations mention aspects such as quality in the genetics of the seed, fumigation period, leaving a period free of sowing to interrupt mite production, initiate observation, monitoring and control of the mite as close to the sowing period, and avoiding late applications with systemic products of high toxicity for public health among other aspects [15].

Barahona-Amores *et al* [16] concluded that each rice´s variety presented different nutrient absorption which suggests an adjustment in the fertilization plants that are currently managed. In Panama, the rice production activity is carried out by 1,185 rice producers, with the provinces of Chiriquí, Panama (east) and Darién being the ones with the largest cultivation (See table 1). According to the table 1, the provinces of *Chiriqui, Panama Este and Darién* correspond to 70.1 % of the national rice production.

TABLE 1: TOTAL RICE PLANTED IN PANAMA COUNTRY[18].

Province	Hectares	Percentage
Chiriquí	9,502	38.5%
Panamá Este	3,999	16.3%
Darién	3,773	15.3%
Veraguas	3,726	15.2%
Los Santos	1,661	6,8%
Coclé	1,425	5,8%
Herrera	412	1,7%
Panamá Oeste	90	0,4%

More than half of the rice harvest in Panama is carried out during the months of September (17.8%), October (15.2%) and November (21.6%) respectively [5]. The Ministry of Agricultural Development (MIDA) classifies the country into ten agricultural regions. In the analysis period from 1999 to 2016, most of the national commercial rice production has been developed in region-1, that is, the province of Chiriquí with 45.7%. Followed by Region-4 Coclé with 17.1% and in third position is Region-2 Veraguas with a contribution of 12.4%. The regions with the lowest rice production are Region-9 of *Bocas del Toro* and Region-5 of *Panama Oeste* with 1.2% and 0.05% respectively [5].

According to data from MIDA (2019), 25% of the areas planted with rice use the irrigated production system and 75% of the areas planted with rice use the rainfed production system. With this relationship, a great potential for growth in rice production in Panama is observed, as long as economic agents make planning aimed at investing in technologies that allow increasing the productivity of the crop and that the state policy to support the sector agriculture is directed towards the technological transformation of planting systems, specifically irrigation systems [19].

In recent years, Rice activity has been affected by weather events such as floods and droughts, the impact by pests such as the S. Spinky mite, which caused a reduction in production by up to 60% and a decrease in production, due to the use of seeds of low genetic quality. In La Prensa (2014), found in FAO documents, it states that all these events have resulted in the withdrawal of a considerable number of economic agents or producers from this economic activity, since 30 of them could not cope with their debts, and consequently there was a reduction in the area cultivated with rice. This, together with the lack of agricultural policies and financing lines, has contributed to a deterioration in the national supply of the product, specifically the contribution of national production [19].

On the other side, the effects of climate change and its impacts on different productive sectors [6] have become evident, particularly those of medium and small scale agricultural activity and this puts the food security of the most exposed populations at risk. This situation requires that climate risks be managed. Since 2010, more than 3,000 producers have been affected, a figure that continues to increase over time due to the high level of vulnerability of their production systems [6]. Rice pests, weeds and insects are responsible for a 35% loss in production. In the situation of irrigated rice, insect and pest management represents 6% of production costs. In Panama, similar results were obtained thanks to Zachrisson in 1998, where the production cost in terms of insect control in rice, under irrigation conditions, was 7%, therefore, insects were considered a limitation of great importance for the development of rice production [20].

According to the 2015 annual report of the *Contraloría General de la República de Panamá*, which oversees national statistics through the National Institute of Statistics and Census of Panama (INEC), the gross agricultural value added registered a slight growth of 0.4 % in relation to 2014. On the one hand, some activities achieved increases, such as rice cultivation (3.5%), due to a greater area planted and harvested; as well as the production of bananas (4.7%) and melons (17.9%), due to greater external demand. On the other hand, the production of watermelon (-9.5%) and pineapple (-31.4%) registered negative performances, due to their lower exports [6].

According to IMA (2019), in Panama there are 48 industrial facilities that are dedicated to the processing of Paddy or husk rice. The private company carries out 85% of the piling process and has 72% of the storage capacity. The installed capacity in the country to store paddy rice is 5.9 million quintals [19].

The demand for white or milled rice has been maintained and shows upward trends due to the increase in the population, which has gone from 2.9 million inhabitants in 2000 and a demand for milled rice from 3.8 million quintals to 3.5 million inhabitants. In 2010 and an approximate demand for rice of 7 million quintals for 2019 [19].

The table 2 presents the values of the sums insured for each of the provinces of Panama and according to the harvest area in the country for the period 214-2015. The table 2 shows the provinces of Veraguas, Chiriquí and Coclé occupy the first three places respectively. The total planted area throughout the country, including the regions, corresponds to 89,190 hectares.

TABLE 2. PANAMA: SUM INSURED BY PROVINCE AND CROP ACCORDING TO HARVEST AREA, 2014-2015 [6].

Province	Cost of rice by province (in American dollars) [6]	Rice planted area (hectares) [6]	Percentage
Veraguas	35834000	18860	21.15
Chiriquí	34352000	18080	20.27
Coclé	31084000	16360	18.34
Los Santos	19095000	10050	11.27
Panamá	16948000	8920	10.00
Darién	10773000	5670	6.36
Ngäbe-Buglé	9481000	4990	5.59
Herrera	5985000	3150	3.53
Bocas del Toro	1805000	950	1.07
Colón	1729000	910	1.02
Guna Yala	133000	70	0.08
Emberá	2242000	1180	1.32
Totales	**169461000*** cifra corregida	**89190**	**100.00**

TABLE 3. ANALYSIS OF MEASURES OF CENTRAL TENDENCY

Mean	7432.5
Median	5330
Variance	44833268.75
Standard deviation	6993.50
Coefficient of asymetry (skewness)	0.5941
Kurtosis	-1.09
Coeficient of variation	94.09

Table 3 presents the results of the statistical analysis of measures of central tendency by table 2. The mean value of all provinces and indigenous reserves is 7432.5 hectares with a standard desviation of 6993.50. The coefficient of asymmetry or skewness corresponds to the value 0.5941. It is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. In this case, the skewness is positive (Skewness >0). The right tail is longer, and most of the distribution is centered to the left of the picture. The distribution is said to be right-skewed, right-tailed, or skewed to the right, even though the curve itself appears to be skewed or leaning to the left; right instead refers to the right tail being drawn out and, in many cases, the mean being skewed to the right of a typical center of data. A right-skewed distribution typically appears as a left-leaning curve. A positive/right skew indicates that the mean is bigger than the median value (7432.5 > 5330).

III. MATERIALS AND METHODS

The data and methodology used corresponds to:

Data collection. It corresponds to:

- Database of the *Contraloría general de la República de Panamá* and others: [21] [22][23][24], [25][26].
- Database of the *Ministerio de Desarrollo Agropecuario de Panamá* (Ministry of Agricultural Development of Panama).

The *Instituto Nacional de Estadística y Censo* (INEC) of the *Contraloria General de la Republica de Panamá* published the results of the Agricultural Survey of Rice, Corn, and Beans conducted in June of each year. This survey includes information on the planted area and harvest of paddy, wet, and dirty rice, corn in quintals of dry grain and new cobs, as well as vine beans in quintals of dry grain for the agricultural year. This information is obtained through statistical sampling in the country's ten provinces and the *Ngäbe Buglé* indigenous region.

The Agricultural and Fisheries Statistics Section, together with the Sampling Department of the INEC, periodically updates the selected sample, primarily of specialized producers (companies, organizations, and large farms). This update incorporates new producers into the sample not included in the sampling frame. They plant using mechanized methods and receive technical assistance from *Ministerio de desarrollo agropecuario* (MIDA)[27].

This INEC[27] publish information regarding the different types of farms and the different planting periods. In addition, it is possible to find data on the planting methods used, fertilizer application, use of certified seed, harvest utilization, land ownership, quantity and value of imports, and annual average prices received, as well as an explanation of the reliability of the estimates for the crops studied.

This survey was part of the annual continuous agricultural statistics program that began in 1952 by INEC.

The data collection corresponds to 5 cases, these being:

- Case Nº1: 2015-2024 vs Total harvest of the Republic of Panama,
- Case Nº2: 2015-2024 vs Harvest in Veraguas,
- Case Nº3: 2015-2024 vs Harvest in Coclé,
- Case Nº4: 2015-2024 vs Harvest in Chiriquí,
- Case Nº5: 2015-2024 vs Harvest in the province of Panama.

Build the analysis matrix system (Excel). Table 4 presents the Harvest vs planted area in the Republic of Panama, Veraguas, Cocle, Chiriqui and Panama (province).

TABLE 4. HARVEST VS PLANTED AREA IN THE COUNTRY AND PROVINCES

1: Periods, B: Harvest (quintals), C: Planted area (hectares)										
	Panama country		Veraguas		Coclé		Chiriquí		Panama province	
1	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**
15/16	6244900	93630	1289200	18400	812300	13950	1909500	21170	842200	11620
16/17	7116700	92520	1258700	15050	1070200	14340	1925500	21630	1072700	13160
17/18	7003900	94450	1346300	16860	1061500	15360	1917300	21300	932500	12480
18/19	7444900	97140	1245000	15630	1136400	15110	2136800	21650	1031900	14580
19/20	7832000	99870	1359200	16790	1188900	15380	2207300	21980	1103000	15330
20/21	8127400	98040	1331000	15520	1241800	14590	2255400	22030	1246400	14680
21/22	8630100	97920	1434200	14630	1255100	15370	2455500	22430	1289600	15580
22/23	8722700	101370	1498500	17990	1343000	15740	2520900	24210	1332700	15230
23/24	9616332	92757	--------	11269.50*	-------	11630.60*	-------	21855.20*	-------	1749570 *
24/25	-------	100,000*	-------	-------	-------	-------	-------	-------	-------	-------

→ Statistical tool: Regression statistical analysis. Regression analysis is a statistical process that allows us to analyze the relationship that exists between two or more variables, one of them being dependent on the rest of the variables that we are using in our mathematical calculation. In other words, a regressive analysis makes it possible to understand how independent variables directly affect another variable that depends on them.

The variables of regression statistical analysis are:

X: Always surface area (hectares).

Y: Rice harvest (quintals).

By the case n°1 (Panama country), table 4 presents the period of greatest harvest was 23/24 with 9,616,332 quintals with an area of 92,757 hectares. However, in the 15/16 period, we found the period of smallest harvest with quintals 6,244,900 quintals with an area of 93,630 hectares. By the case n°2, province of Veraguas, the table 4 shows that the period of greatest harvest was 19/20 with 1359200 quintals, with an area of 16790 hectares and it turned out to be more efficient compared to the 15/16 period since in this period a total of 128900 were obtained. quintals, less than in the 19/20 period, with a larger planting area, being 18,400 hectares. By the case n°3, province of Cocle, table 4 shows the period of greatest harvest was 22/23 with 1,343,000 quintals with an area of 15,740 hectares. The period with the smallest surface area was 15/16 with 812,300 quintals with an area of 13950 hectares. By the case n°4, province of Veraguas, table 4 shows the period of greatest harvest was 19/20 with 2,207,300 quintals, with an area of 21,980 hectares. It is reflected that starting in the 18/19 period there was a more efficient harvest according to the surface-crop ratio. The clearest example of this is shown when comparing the periods 16/17 and 18/19, in which, with a difference of only 20 hectares, the period 18/19 obtained a larger harvest with a difference of 211,300 quintals. By the case n°5, province of Panama, table 4 shows the period of greatest harvest was 22/23 with 1,332,700 quintals with an area of 15,230 hectares. The period of the smallest harvest was 15/16 with 842000 quintals with an area of 11620 hectares.

IV RESULTS

Table 5 presents the results of the best regression fit curves for each of the 5 case studies, with their respective correlation and determination coefficients. The best characteristic equation resulted in polynomials of degree 6 compared to linear and exponential regressions, since these resulting equations yielded the highest correlation and determination coefficients with values close to 1. Due to the values of the resulting coefficients for the terms of degrees 6 and 5, they were eliminated to leave them with coefficients of degree 3 and 4, without affecting the results. Correlation, also known as linear correlation coefficient (Pearson), is a regression measure that aims to quantify the degree of joint variation between two variables. According to Navidi [28], the correlation coefficient is defined, which is a numerical measure of the strength of the linear relationship between two variables. This coefficient is denoted by the literal r. The purpose of correlation is to examine the direction and strength of the association between two quantitative variables. This way we will know the intensity of the relationship between them and if, by increasing the value of one variable, the value of the other variable increases or decreases. $r = -1 \Rightarrow$ perfect negative linear association between x and y

$r = 1 \Rightarrow$ perfect positive linear association between x and y

$r = 0 \Rightarrow$ there is no linear association between x and y

X: Planted area surface (hectares)

Y: Rice harvest (quintals)

TABLE 5. CHARACTERISTIC EQUATION, CORRELATION AND DETERMINATION COEFFICIENTS BY CASE.

1: province 2: characteristic equation 3: correlation coeficient (R) determination coefficient (R^2)				
#	1	2	3	4
1	Panamá country	$y=6E+06e^{0.0474x}$	0.9830	0.9663
2	Veraguas	$y = 0.0002x^4 - 4.9358x^3 + 60819x^2 - 4E+08x + 1E+12$	0.9613	0.9241
3	Coclé	$y = - 0.173x^4 + 3421x^3 - 4E+07x^2 + 2E+11x - 6E+14$	0.968	0.937
4	Chiriquí	$y = - 0.0202x^4 + 595.65x^3 - 1E+07x^2 + 9E+10x - 3E+14$	0.9749	0.9505
5	Panamá (province)	$y = 0.0013x^4 - 22.985x^3 + 236149x^2 - 1E+09x + 3E+12$	0.9923	0.9847

As can be seen in table 5, case No. 5 (Panama-province), the Panama harvest has the highest correlation coefficient, this is 0.9923, while case No. 2, the harvest in Veraguas, has the lowest correlation coefficient. with 0.9613. The first three places in terms of correlation coefficient after the country coefficient are: Panama province (0.9923), Panama country (0.9830) and Chiriquí (0.9749). The coefficient of determination determines the quality of the model to replicate the results, and the proportion of variation in the results that can be explained by the model [29]. For linear regression, R^2 is simply the square of the Pearson correlation coefficient, which is only true for simple linear regression. The characteristics of this coefficient of determination [30] are:
R2 is a dimensionless quantity that can only take values in [0, 1].

- When a fit is good, R2 will be close to one (the stronger the association between both variables will be).
- When a fit is bad, R2 will be close to zero (the line explains nothing, there is no association between X and Y).

The table 5, case No. 1, the Panama province harvest has the highest coefficient of determination, this is 0.9847, while case No. 2, the harvest in Veraguas, has the lowest coefficient of determination. with 0.9241. With respect to the characteristic equation, Table 8, the dominant equations are practically linear for cases 2, 3, 4 and 5, since the terms with exponents of the fifth and sixth degree have very small values of the order of 10^{-14} and 10^{-6} respectively. Case 1 corresponds to an exponential equation.

V DISCUSSION

5.1 Summary of the main findings

- The province of Chiriquí had the highest efficiency in rice production, with a greater number of quintals gathered from a smaller planting area.
- Rice production has varied across the country; the maximum yield, 9,616,332 quintals from 92,757 hectares, was recorded in 2023–2024.
- There is a significant relationship (R > 0.96) between planted areas and yield, suggesting that better agricultural practices could maximize output without necessarily requiring more land use.
- According to Díaz- Márquez [19]75% of rice farms depend on rainfed cultivation, making them vulnerable to climatic hazards like floods and droughts that have decreased output by up to 60% in some areas.
- Low-quality seeds and pests have been major contributors to output losses; managing insects and pests accounts for roughly 6–7% of production expenses [20].
- Population expansion has increased demand for rice, but national output has not kept up, resulting in a reliance on imports [31].

5.2 Improving Panama's Rice Production: Policy Suggestions

Background. One of Panama's most vital basic commodities, rice plays a vital role in the country's nutrition, especially for those with lower incomes. Rice is a vital component of the nation's food security since it is its main energy source. Despite its importance, Panama's rice industry suffers several difficulties, such as inconsistent yields, ineffective farming practices, dependence on rainfed production, pest problems, and restricted access to new technologies.
In Panama, the provinces of Chiriquí, Veraguas, Coclé, and Panama produce most of the country's rice. With an average daily consumption of 158 grams of rice per person, the nation has one of the highest rates of rice consumption in Central America [5]. The inability of domestic output to meet demand, however, has resulted in sporadic imports to maintain supplies [31].
Furthermore, yields have been impacted by climatic variability increasingly, with extreme weather events and unpredictable rainfall patterns resulting in large losses. Fertility and total output have been further diminished by soil degradation brought on by overpreparation, erosion, and compacted layers. To guarantee sustainable rice production and national food security, these variables call for immediate governmental actions

5.3 Proposals for Development

- **Investing in infrastructure for irrigation.** Expanding irrigation infrastructure would stabilize production and reduce climate-related losses, as 75% of rice agriculture is rainfed. To finance these investments, public-private partnerships may be investigated.
- **Encouraging Premium Seeds and Integrated Pest Control.** Productivity can be greatly increased by implementing sustainable pest management techniques and stepping up the usage of genetically superior seeds. Farmers who use integrated pest management strategies and certified seed varieties ought to get government incentives.
- **Strengthening Research and Development.** Research projects to enhance soil fertility, optimize planting cycles, and create climate-resilient rice cultivars should involve cooperation between public and commercial institutions. Long-term productivity increases can be fueled by increased financing for agricultural R&D.
- **Farmers' Access to Financial Mechanisms.** To make it easier for small and medium-sized farmers to invest in

new farming methods and equipment, a specialized agricultural finance program should be created.

- **Knowledge sharing and digitization.** To provide up-to-date information on pest outbreaks, weather trends, and best agricultural practices, the government should support digital platforms. Programs to increase capacity should be put in place to teach farmers how to make decisions based on data.

- **Creating Strategies for Risk Management.** To shield farmers from losses brought on by climate change, index-based agriculture insurance ought to be implemented. More adoption and resilience in rice cultivation can be fostered by subsidized insurance programs.

In brief, this study contributes to understanding the dynamics of rice production in Panama, a staple food in the national diet. Analyzing the relationship between cultivated areas and yield allows for the identification of production trends and potential opportunities to improve the sector's efficiency.

Secondly, the study highlights the need to strengthen agricultural productivity through technological innovation and agricultural planning, especially in the face of challenges such as climate change, pests, and climate variability that affect the rice sector.

Furthermore, the document emphasizes the importance of statistical analysis and modeling in agriculture, tools that can support decision-making in public policy, land-use planning, and production strategies.

As future research lines, the authors recommend incorporate additional variables like: climatic conditions, agricultural technology, crop management, costs, input quality that will allow extend the analysis.

VI CONCLUSIONS

The construction of robust mathematical models makes it possible to guide and update the design, execution and evaluation of public policies regarding agricultural production projections of sensitive items of the country's basic food basket. This article has determined efficiency indicators for 5 cases of harvests, these being: the harvest of the entire country, and the provinces of Chiriquí, Veraguas and Coclé. The correlation indices have shown in all cases a positive linear association correlation between hectares planted and quintals harvested. The correlation coefficients range between 0.9923 and 0.9613. Regarding the coefficient of determination, all cases have a good fit, R^2 will be close to one (the stronger the association between both variables will be). Although Panama's rice industry is essential to the country's food security, it faces major obstacles in terms of sustainability and productivity. A multidimensional strategy is needed to address these issues, one that involves funding irrigation, promoting premium seeds, improving research and development, giving farmers better access to financing, and digitizing agricultural data. Panama can increase rice productivity, lessen its reliance on imports, guarantee long-term food security for its expanding population, and even turn into a competitive rice exporter once more by putting these policy measures into place. To promote innovation and resilience in the rice industry, a concerted effort including government organizations, private sector participants, research institutes, and farmers is required. A more competitive and sustainable rice sector in Panama may result from wise investments and well-executed regulations.

ACKNOWLEDGMENTS

The subject of this publication was carried out by an international and intercontinental scientific research team with practical competences: the Universidad *Tecnológica de Panamá* (Panama) and *Universidad Politécnica de Madrid* (Spain).

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