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Unraveling the Dynamics of Rice Yield in the Zio River Valley, Togo: A thorough analysis of influencing factors

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Abstract

Despite Togo's rice production potential, local production only meets 32% of demand, mainly due to relatively low agricultural productivity. With the aim of improving this situation, this study was undertaken to analyze the factors influencing rice production in the Zio River Valley, which is one of Togo's largest rice-growing areas. Data collected from 413 farmers in the region were analyzed using the Cobb-Douglas production function, incorporating variables such as income, farm size, chemical fertilizer use, organic fertilizer use, pesticide use, group membership, experience, education level, gender, access to credit, access to agricultural advice, age, continuous access to water and marital status. The results indicate that only certain factors, such as farm size, income, amount of chemical fertilizer, use of organic fertilizer and experience, have a significant positive impact on paddy rice production, furthermore the No-formal education farmers show a decrease in production. This study will guide decision-makers and farmers in adopting more effective farming practices to significantly improve rice production in Togo. Emphasis should be placed on aspects such as farm size, income, fertilizer use and experience to boost rice productivity.

Keywords: Rice production; Agricultural productivity; Zio River Valley; Cobb-Douglas production function

JEL code: Q19

1. Introduction

A staple food, rice is the most important food crop in developing countries, feeding more than half the world's population. Consumption exceeds 100 kg/capita/year in many Asian countries. It averages 70 kg in the Caribbean, 45 kg in Latin America and 30 kg in sub-Saharan Africa (60 kg in West Africa excluding Nigeria). More than 3.5 billion people worldwide depend on rice for over 20% of their daily caloric needs [1].

Rice production is a major issue for food security and economic development in Togo. Nationally, rice has become the second most consumed cereal after maize, with annual consumption of around 300,000 tonnes [2]. The Togolese government is striving to increase national rice production in order to reduce dependence on imports and make this cereal accessible to the population.

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Despite the enormous rice production potential available in Togo, local rice production only covers 32% of demand [3]. Togo's rice production like other sub-Saharan countries cope with numerous challenges that limit its productivity and expansion [4,5]. The irrigated perimeter of the Zio River Valley, with a surface area of around 850 ha, is one of the largest developed perimeters where rice cultivation has been practiced since 1965. Over the years, average yields have fallen steadily [FAO & MAEDR, (2021). National Development Plan for the Rice Sector in Togo (2021-2030), (June 2021 version). from 6-7 t. ha-1 between 1966 and 1971 to 3.8 - 4.2 t. ha-1 from 1972, and now stand at 1.5 - 2.5 t. ha-1 [6].

In this study, we focus on the key factors influencing rice production in the Zio river valley, focusing on socio-economic and technical factors. According to the literature, socio-economic factors play a major role in rice-crop productivity in Africa, alongside agro-climatic and technical factors [7,8]. In general, some authors emphasize that the advanced age of producers, their low level of education, their lack of access to inputs and financial services, and their low degree of organization severely limit productivity [3,7,8,9]. [10] highlighted the crucial role of agricultural extension services in improving rice production. [11] revealed as well the importance of water management and accessibility for rice production. [12] highlighted the role of agricultural cooperatives in improving rice production.

Based on the hypothesis that socio-economic and technical factors influence the productivity of rice on the irrigated perimeter of the Zio River Valley, this study seeks to understand how these factors interact and impact rice production, focusing on the social-economic and technical aspects that can be decisive in improving yields in addition to other agro-climatic factors.

Data was drawn from a variety of sources to support this study analysis, a survey was carried out in June 2023 with 413 rice producers in the Zio Valley irrigated perimeter, interviews with agricultural extension services and previous studies on rice production in the area.

2. Materials and methods

2.1. Presentation of the study area

The perimeter of the Zio river valley is a site located between 6°23'13.54" / 6°19'25.90" latitude North and 1°6'30.13" / 1°8'52.62" longitude East. This is a perimeter of around 850 ha developed as rice paddies in the prefecture of Zio at the intersection of the communes of Davie, Mission-Tove, Kovié and Wli. This perimeter, used exclusively for rice cultivation, can be subdivided into 2 main zones, according to the number of years the land has been farmed (Fig1): The first zone is the old perimeter (progressively developed from 1965 onwards), with a surface area of around 600 Ha. The second zone is considered to be the new perimeter (developed in 2012), with a surface area of around 250 Ha.

The area enjoys a Sudano-Guinean climate, with an average annual temperature of 26°C and an average annual relative humidity of 81.5%. There are 2 rainy seasons and 2 dry seasons: the long rainy season runs from March to July and the short rainy season from September to November. The long dry season runs from December to March, and the short dry season is August.

2.2. Sampling

The study focused mainly on rice growers exploiting rice on the developed perimeter of the Zio river valley, who are distributed essentially in the localities of Wli, Assomé, Kovié and Mission Tové, as well as certain surrounding localities such as Bolou. Sampling was based on Cochran's sampling formula:

Table 1 Standard formula for estimating a sample from a known target population

Formula for estimating the sample size to be surveyed	
Formula: $n = t^2 \times p \times (1-p) / m^2$	Where: n: Minimum sample size to obtain significant results for a given event and risk level t: Confidence level (the standard value for the 95% confidence level is 1.96) p: estimated proportion of the population with the characteristic m: Margin of error (5%)

2.3. Data collection

Qualitative and quantitative data were collected using the KoboCollect application, which was deployed on the tablets of 11 interviewers. Data were collected from 413 producers, covering their socio-economic characteristics (gender, age, level of education, marital status, religion, membership of a group/cooperative, access to credit, household size, etc.), areas sown, whether or not chemical pesticides were used, whether or not chemical and organic fertilizers were used, cultivation practices, etc. the data were collected in June 2023 by administering a questionnaire (direct interview) to the producers met on the agricultural perimeter. this survey was therefore carried out exclusively on the irrigated perimeter of the Zio Valley in Togo, which represents our study area. the producers surveyed were selected at random to answer the questions.

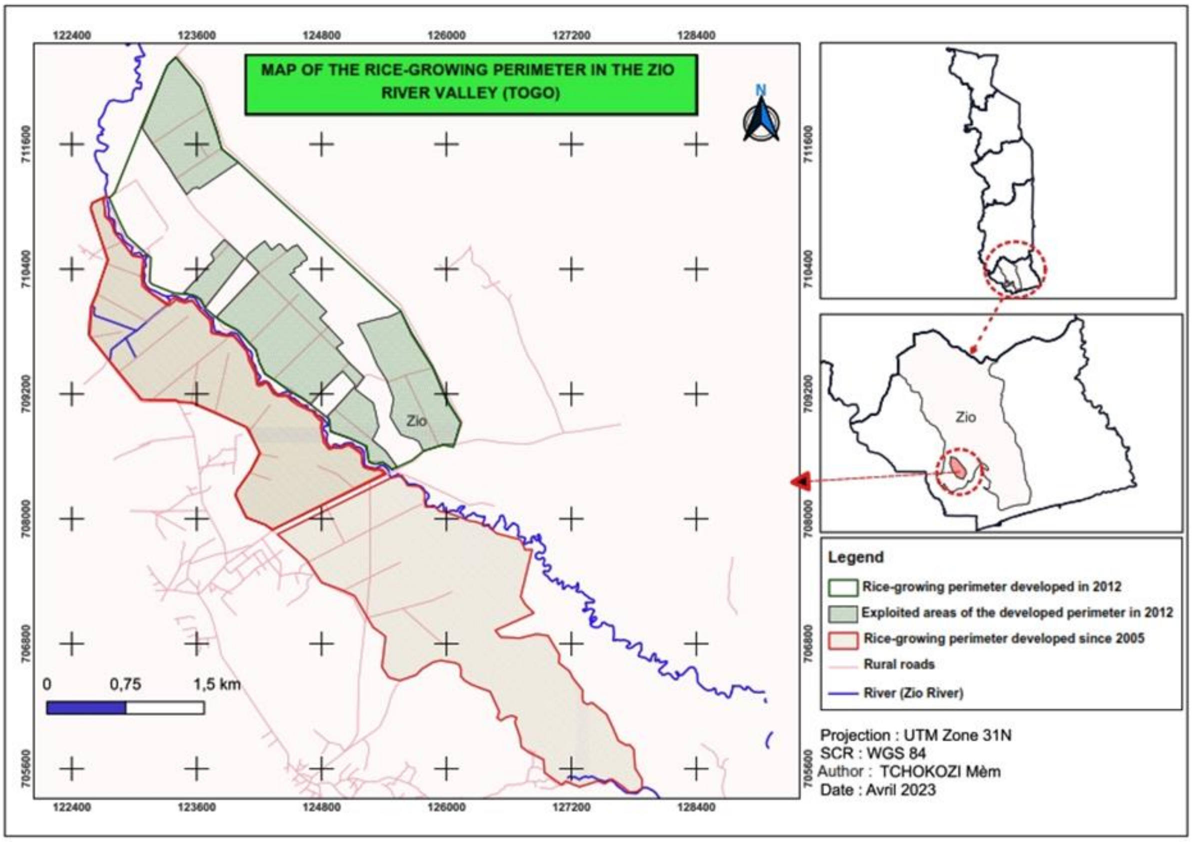

Figure 1 Overview map of the study area (Source: Author, 2023)

2.4. Analysis method

To achieve this study objectives the cobb-Douglas production function was used. The Cobb-Douglas production function is an economic model used to represent the relationship between factors of production (labor and capital) and the output of a company or economic sector. It is widely used in agricultural economics to study agricultural productivity [13]. This function was preferred because it facilitates the characterization of constant returns to scale, meaning that if all factors of production are multiplied by a certain factor, output will be multiplied by the same factor [14]. Conversely, it is also characterized by diminishing marginal returns, meaning that an increase in one factor of production leads to an increase in output, but at a diminishing rate. It is a model that is widely used to analyze the effects of changes in labor and capital levels on agricultural production, as well as to assess the effectiveness of agricultural policies and agricultural technologies [15]. For example, a study published by [16] entitled Inputs, Productivity and Agricultural Growth in Sub-Saharan Africa " also used the Cobb-Douglas production function to analyze the impact of agricultural inputs on crop productivity in Senegal. The authors found that the use of fertilizers, improved seeds and labor had a positive and significant impact on crop productivity, confirming the relevant use of the Cobb-Douglas production function in this study.

The Cobb-Douglas production function specification:

$$\boldsymbol{Y = AL^{\alpha}K^{\beta} \ldots S^{i}} \quad (1)$$

Where

Y represents total production,

L represents the quantity of labor used,

K the quantity of capital employed,

and **S** any other factor entering in the production process.

A is total factor productivity or production efficiency,

α, **β** and **i** are the parameters that measure the elasticity of the production with respect to labor, capital any other factor

The linearized function:

$$\boldsymbol{LnY = lnA + \alpha lnL + \beta lnK + \cdots ilnS} \quad (2)$$

which could be written as:

$$\boldsymbol{lnY = \beta_0 + \beta_1 lnL + \beta_2 lnK + \cdots \beta_i lnS + \mu_i} \quad (3)$$

$\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \boldsymbol{\beta_i}$ parameters to be estimated

$\boldsymbol{\mu_i}$ the error terms

Replacing the different factors entering in this study into equation (3) will give:

$$\boldsymbol{Y = \beta 0 + \beta 1 lnArea + \beta 2 lnFarmer\_Income + \beta 3 lnChmq\_Fertilizer\_Quantity + \beta 4 Org\_Fertilizer\_Use + \beta 5 lnChmq\_Pesticide\_Quantity + \beta 6 Group\_Appartment + \beta 7 Expce\_Producer + \beta 8 Education + \beta 9 Gender + \beta 10 Acc\grave{e}s\_cr\acute{e}dit + \beta 11 Acc\grave{e}s\_Conseil\_agricol + \beta 12 Age + \beta 13 EAcc\grave{e}s\_eau + \beta 14 St\_Matrimonial + \mu i} \quad (4)$$

Explanatory variables introduced into the model are summarized in Table 2 below:

Table 2 List of variables used in this study and their modalities (Source: Results of survey analyses)

Variables	**Modalities**
Surface area (m^2)	Continuous
Farmer's income (in F CFA)	Continuous
Quantity of chemical fertilizer per (Kg/Ha)	Continuous
Use of organic fertilizers	1=YES 0=NO
Chemical pesticide quantities (l/Ha)	Continuous
Membership of a group or cooperative	1=YES 0= NO
Experience in rice production (Year)	-

Variables	Modalities
Education level	1-No formal education, 2-Primary, 3-Junior high-school, 4-Senior High-school, 5-University+.
Genre	1=Male 0= Female
Access to credit	1=YES 0= NO
Access to farm advisory services	1=YES 0=NO
Age	Continuous
Access to water all year round	1=YES 0=NO
Marital status of farmer	1-Single, 2-Married, 3-Others

3. Results

3.1. Socio-economic characteristics of growers

3.1.1. Qualitative variables

As shown in Table 3, the results of this study indicate an unequal gender distribution among farmers, with a majority of 86.68% male farmers compared with only 13.32% female farmers. As for membership of a group/cooperative, 51.33% of farmers said they were affiliated to one, while 48.67% said they were not. In terms of marital status, the vast majority (88.14%) of farmers are married, while 9.44% are single and only 2.42% are others. In terms of level of education, the majority of farmers (42.62%) have primary school education, followed by secondary school (25.42%), no formal education (20.82%) and high school (9.44%). Only 1.69% of farmers had reached university level or higher, indicating a significant disparity in terms of education among the population studied. In terms of access to credit, a large majority (86.68%) of farmers said they had access, while 13.32% said they did not. In terms of access to agricultural advice, the results show that 37.53% of farmers have access to regular agricultural advice, while 24.21% do not, and 38.26% have sporadic access. Finally, with regard to the difficulty of accessing water in all seasons, 63.68% of ex-farmers said they had no difficulties, while 36.32% said they had difficulties accessing water in all seasons. These results underline the importance of taking into account disparities in gender, group/cooperative membership, marital status, level of education, access to credit, access to agricultural advice and difficulty of access to water when identifying factors determining rice productivity in the irrigated perimeter of the Zio river valley.

Table 3 Table of qualitative variable statistics (Source: Survey analysis results)

Variables	Numbers	Frequencies
Gender		
Female	57	13,32%
Male	356	86,68%
Group/cooperative membership		
YES	212	51,33%
NO	201	48,67%
Marital status of operator		
CELIBATE Single	39	9,44%
MARIE Married	364	88,14%
Others	10	2,42%
Operator's level of education		
No-formal education	86	20,82%
Primary level	176	42,62%

Variables	Numbers	Frequencies
Middle school level Junior High-school	105	25,42%
High school Senior High-school	39	9,44%
University and above	7	1,69%
Access to credit		
NO	55	13,32%
YES	358	86,68%
Access to farm advisory services		
YES	155	37,53%
NO	100	24,21%
SOMETIMES	158	38,26%
Difficult access to water in all seasons		
NO	263	63,68%
YES	150	36,32%

3.2. Quantitative variables

The results of the analysis of quantitative variables (Table 4) provide valuable information on the agricultural socio-economic characteristics of the farmers studied. In terms of age, the mean is 42. Age ranges from 20 (minimum) to 72 (maximum). These results indicate a certain age diversity among farmers, ranging from young to more experienced. The average farm size is 16,241 m^2 (1.6 Ha).

Farm areas range from 1,000 m^2 (0.1 Ha) to 100,000 m^2 (10 Ha). These results reflect great variability in the size of the farms studied. In terms of farm income, the average was 2,347,405 F CFA ($4,023), with a median of 1,500,000 F CFA ($2,571). Income varies from 160,000 F CFA ($274) to 28,000,000 F CFA ($47,993). These figures testify to the diversity of income levels among farmers. For chemical fertilizer use, the average quantity used is 399 Kg/Ha, equivalent to 8 x 50 Kg bags. The quantity varies from 100 Kg (minimum) to 850 Kg (maximum), with a standard deviation of 108.85. These results highlight the use of chemical fertilizers on the farms studied. As for the use of chemical pesticides, the average quantity used was 17 liters/Ha, with a median of 16 liters/Ha. Quantities used ranged from 2 liters/Ha (minimum) to 80 liters/Ha (maximum). For the number of years of experience of the grower, the average is 12 years. The number of years of experience varies from 0 to 47 years, with a standard deviation of 8.32.

Table 4 Table of statistics for quantitative variables (Source: Results of survey analyses)

Variables	Mean	Max	Min	SD
Age (year)	42	72	20	10.72
Area (m^2)	16 241	100 000	1 000	15 096
Farmer's income (in F CFA)	2 347 405	28 000 000	160 000	2 843 922
Quantity of chemical fertilizer (Kg/Ha)	399	850	100	108.85
Quantity of chemical pesticides (l/Ha)	17	80	2	8.56
Grower's experience (year)	12	47	0	8.32

3.3. Determinants of rice production

As presented in Table 5, the results of the multiple regression analysis indicate how the different variables in the model concretely contribute to the increase or decrease in paddy rice production. Based on the estimated values, the area variable has an estimated coefficient of 0.5293 ($p < 0.001$), meaning that a 1% increase in farm area is associated with a 0.53% increase in paddy rice production on the perimeter. Thus, a larger farm area contributes significantly to an increase in paddy rice production. Farmer income (FCFA) has an estimated coefficient of 0.3130 ($p < 0.001$), indicating that a 1% increase in farmer income is associated with a 0.3% increase in paddy rice production. Therefore, higher farmer income is associated with a significant increase in paddy rice production.

The variable Quantity of fertilizer (Kg/Ha) has an estimated coefficient of 0.1996 ($p = 0.0051$), suggesting that a 1% increase in the quantity of fertilizer used per hectare is associated with a 0.2% increase in paddy rice production. Thus, under current production conditions, the use of a greater quantity of fertilizer could have a positive impact on paddy rice production on the perimeter. Also, the use of organic fertilizer by some producers obtained an estimated coefficient of 0.4409 ($p = 0.0294$), indicating that the use of organic fertilizer is associated with a 0.4% increase in paddy rice production. Consequently, the adoption of agricultural practices using organic fertilizers can contribute significantly to increasing paddy rice production.

With regard to the number of years of experience of the producer, the estimated coefficient is 0.0079 ($p = 0.0101$). This means that an increase of one year in producer experience is associated with a 0.0079% increase in paddy rice production. Thus, greater producer experience in paddy rice cultivation can have a positive impact on production.

Table 5 Production factor modeling (cobb-douglas model)

ln Production Rice paddy (Kg)	**Estimate**		**Std.error**	**Z-Value**
(Intercept)	-2.7306	***	0.5625	-4.8544
lnArea (m^2)	0.5293	***	0.0373	14.1720
lnFarmer's income (FCFA)	0.3130	***	0.0310	10.0821
lnQty of fertilizer (Kg/Ha)	0.1996	**	0.0709	2.8153
Use_Organic fertilizer YES	0.4409	*	0.2016	2.1871
lnQty of pesticides (l/Ha)	0.1149	**	0.0432	2.6579
Group/Cooperative membership	-0.0332		0.0441	-0.7532
Number of years of experience (years)	0.0079	*	0.0031	2.5865
Education_LEVEL LYCEE	0.0291		0.0744	0.3917
Education_LEVEL COLLEGE	-0.0222		0.0506	-0.4388
Education_NOT INSTRUCTED	-0.1401	*	0.0546	-2.5674
Education_LEVEL UNIVERSITY AND OVER	0.2096		0.1565	1.3389
Gender	-0.0605		0.0631	-0.9585
Access to credit	0.0565		0.0633	0.8938
Access to agricultural advice	-0.0150		0.0245	-0.6102
Age (year)	-0.0019		0.0024	-0.7645
Access to water at all times	-0.0148		0.0448	-0.3301
Status_Matrimonia_MARIEE	0.0755		0.0758	0.9963
Status_Matrimonial_VEUF(VE)	-0.0430		0.1513	-0.2845
F-statistic: 74.08 on 18 and 376 DF, p-value: < 2.2e-16				

Overall, the regression model shows good statistical significance and is able to explain a large part of the variation observed in paddy rice production on the perimeter. The model's main performance measures are as follows: Mul-tiple R-squared (R^2): This coefficient of multiple determination indicates that the model explicates around 78% of the total variation in paddy rice production. This suggests that the variables included in the model capture a significant proportion of the variability in production. Adjusted R-squared: This measure takes into account the number of independent variables and the number of observations. Adjusting the R-squared controls the addition of unnecessary variables. Here, the adjusted R^2 is around 76.95%, which indicates that the model retains good explanatory power even after taking model complexity into account. In our case, the F-statistic is 74.08 with a very low p-value (< 2.2e-16), confirming that the model as a whole is statistically significant.

4. Discussion

The results of the factor analysis show that farm size has a highly significant effect on paddy rice production. Indeed, according to a recent study by [17] on factors influencing paddy rice productivity in Mali's Office du Niger, it was found that an increase in farm area significantly contributes to an increase in rice productivity. This conclusion is in line with the results of our model, where the area variable has a positive and significant estimated coefficient. [18], in his study " The supply of rice to Madagascan farming households: an econometric study based on cross-sectional surveys ", also concluded that the price elasticity of supply increases with the area cultivated, confirming the result of our model. Despite the methodological difference used, [19], using the stochastic production frontier technique, also highlighted a larger and more significant marginal effect for the farm size variable. An increase in farm size associated with a significant increase in paddy rice production on the perimeter can indeed be explained by the fact that farmers owning large farms invest sufficiently, given the importance of this activity in their sources of income.

With regard to the "producer income" variable, [19] and [20] highlighted the importance of farmer income in paddy rice production. Their results showed that higher farmer income was associated with a significant increase in paddy rice production. This conclusion would appear to be fairly consistent with the nature of rice farming, which in our context requires sufficient financial resources to cover all operating costs, notably investments and production inputs. These results also confirm our findings, where this variable obtained a positive and significant estimated coefficient on the estimated model.

With regard to fertilizer use, a study conducted by [21], entitled " Effect of inorganic fertilizers with organic amendments on soil chemical properties and rice yield in a low-productivity paddy soil", reported the positive effect of mineral fertilizer on paddy rice production. According to [22], who studied the economic and financial performance of fertilization in strict rainfed rice cultivation in the South Sudanian zone of Burkina Faso, they were able to examine and note the positive impact of the quantity of fertilizer used on paddy rice production. Taken together, the authors' results show that increasing the amount of fertilizer used per hectare by a certain proportion was associated with an increase in rice production. This is consistent with the results mentioned above. [23] confirm that the quantity of fertilizer is one of the main factors influencing rice productivities. In their studies, [22] also concluded that in a context of high fertilization costs, it is in the grower's interest to combine organic manure with mineral fertilizers in rice cultivation. Research by [24] has shown that beyond the positive impact of organic fertilizer on rice productivity, the use of organic fertilizer is an important key factor affecting adaptation to climate change.

The farmer's experience in terms of its positive impact on the estimation of our model has also been confirmed by the results of the work of [25]. Indeed, the more years of farming experience a farmer has, the more he masters the itineraries and key elements for optimizing his rice farm. The accumulation of years of experience in rice production would therefore significantly increase the farmer's recorded productivity.

However, it should be noted that other variables such as gender, access to credit, level of education, access to agricultural advice, age, access to water at any time of the season and marital status did not show significant effects on paddy rice production in this study. In fact, the impact of the variables "access to credit" and "level of education on farmers' productivity" have been the subject of several controversies. For some authors, they improve agricultural performance [26,27,28]. For others, however, they have no effect on productivity [29,30]. According to studies by [31] and [32], credit enables the acquisition of inputs that are costly but necessary for production. For the latter, if the funds obtained by farmers through informal or formal lending structures are used to purchase modern inputs, credit has a positive influence on farmers' efficiency. However, credit may not have the positive impact on productivity revealed in our model. Indeed, in our context, the majority of farmers (87%) have access to credit, which enables them to finance their operations. Consequently, credit is no longer a key factor in production.

A particularity of the model used related to the level of education is that having decomposed the level of education of the producer into several modalities, it showed that the variable/modality "producers without any education" have a negative impact on the model with an estimated coefficient of - 0.14, reflecting a decrease in rice production linked to the producer's lack of education. This finding is explained by the authors [33,27] who assert that education should enable farmers to improve their productivity in the sense that an educated agricultural producer easily masters modern production techniques.

For the variables gender and age of the farmer, [34] also concluded that the gender and age of the farmer had no impact on rice productivity, confirming our results. These results can be explained by the fact that most of the operations carried out on the irrigated perimeter of the Zio river valley are often mechanized (clearing, la-bour) and manual operations entrusted to known and experienced workers in the area. These results can be explained by the fact that most of the operations carried out on the irrigated perimeter of the Zio river valley are often mechanized (clearing, ploughing) and manual operations entrusted to known and experienced workers in the area. These results are in contrast to those found by [35], who concluded that, in addition to experience and level of education, age and gender are the factors that significantly influence rice productivity. This difference can be explained by the different context of the studies.

5. Conclusion

The aim of this study was to understand how factors especially socio-economic and technical factors interact and impact on rice production, in order to identify the determining factors in improving paddy rice production in the irrigated perimeter of the Zio river valley in Togo. The results of the factor analysis showed that farm size, farmer income, the quantity of fertilizer used, the use of organic fertilizer and the farmer's experience have a positive and significant effect on paddy rice production. These factors therefore appear to be decisive in improving rice yields in this region. However, other factors such as the farmer's gender, access to credit, level of education, age and marital status do not have a significant effect in this context. Although these factors may influence productivity depending on the angle considered, they do not appear to be determinants of rice production in the Zio river valley. Overall, this study provides useful information to guide interventions aimed at improving rice yields and incomes in the region. Particular attention should be paid to increasing the size of farms, making investments that boost farmers' incomes, promoting improved fertilization practices and building producers' capacities through training.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have no relevant financial or non-financial interests to disclose. We declare that there are no financial interests or personal relationships that could appear to influence the work reported in this article.

Statement of ethical approval

This study did not involve any experiments on human or animal subjects. As such, ethics approval was not required.

Statement of informed consent

This study involved the collection of data from groups of farmers. All participants provided informed consent voluntarily, agreeing to share information about their farming operations to contribute to the findings of this article.

Author Contributions

All authors contributed to the design and development of the study. Mèm Tchokozi, Kwasi Dzola Ayisah, Aboulaye Afoulelou and Gbénonchi Mawussi prepared the material and collected the data. Data analysis and results synthesis were carried out by Mèm Tchokozi and Aboulaye Afoulelou. The first version of the manuscript was drafted by MT, and all authors commented on previous versions of the manuscript. All authors have read and approved the final manuscript.

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