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Impact of drought on the economic profitability of the surface irrigation system for Rice in the Masina Rail 1 site, N'djili Basin, Kinshasa

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Abstract

This article explored the impact of drought on the economic profitability of rice in surface irrigation systems at the Masina Rail 1 site in Kinshasa. Simulation results show that profitability varies significantly by sales unit, with margins reaching up to 3279% during periods of scarcity. In contrast, overproduction leads to a significant decrease in revenues during times of abundance. The sensitivity analysis revealed that all sales units display much higher profit margins during shortages, suggesting that effective management of surface irrigation can make a substantial difference. However, during periods of abundance, margins dropped, with decreases of up to -31.4%, highlighting the risks associated with overproduction. The model validation was promising, showing an adjusted R^2 *of 60.5%, indicating that our model well explains price variation, supported by a statistically significant Fisher test at the 1% level. These analyses demonstrate that managing irrigation is crucial for maximizing profitability, especially during droughts when water becomes scarce. Factors such as price per sales unit and quantity sold are key elements for profitability, while drought and production costs can have negative consequences. Therefore, the study emphasizes the importance for producers to adopt adaptive strategies to improve their economic performance in the face of climatic challenges.*

Keywords: Drought, Watershed, Determinant, Economic profitability, N'djili River

Impact de la sécheresse sur la rentabilité économique du système d'irrigation de surface pour le riz dans le site de Masina Rail 1, bassin de N'djili, Kinshasa

Résumé

Cet article a examiné l'impact de la sécheresse sur la rentabilité économique du riz dans les systèmes d'irrigation de surface au site de Masina Rail 1, à Kinshasa. Les résultats des simulations ont indiqué que la rentabilité varie selon l'unité de vente, avec des marges bénéficiaires atteignant jusqu'à 3279 % dans certains cas pendant les périodes de rareté. Cependant, la surproduction réduit considérablement les revenus en période d'abondance.

L'analyse de sensibilité a démontré que toutes les unités de vente ont montré des marges bénéficiaires significativement plus élevées durant les pénuries, suggérant qu'une gestion efficace de l'irrigation de surface peut améliorer la rentabilité. En revanche, en période d'abondance, les marges bénéficiaires ont diminué de manière marquée, avec des réductions allant jusqu'à -31,4 %, illustrant les risques associés à la surproduction.

La validation du modèle a révélé un coefficient de détermination ajusté de 60,5 %, ce qui indique que le modèle explique une proportion significative de la variance des prix, confirmée par un test de Fisher significatif au seuil de 1 %. Les analyses ont également montré que la gestion de l'irrigation est cruciale pour maximiser la rentabilité, surtout en période de sécheresse lorsque la disponibilité d'eau diminue considérablement. Des facteurs tels que le prix par unité de vente et la quantité vendue sont positivement corrélés à la rentabilité, tandis que la sécheresse et les coûts de production ont des effets négatifs. L'étude souligne la nécessité pour les producteurs d'adopter des stratégies adaptatives pour améliorer leur performance économique face aux défis climatiques.

Mots clés : Sécheresse, Bassin versant, Déterminant, Rentabilité économique, Rivière N'djili-

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INTRODUCTION

Agriculture represents a significant sector of the economy of the Democratic Republic of the Congo (DRC), contributing approximately 45.7% to the gross domestic product (GDP) and employing nearly 80% of the labor force (Ministry of Agriculture, 2018). However, the rapid population growth, which could reach 120 million inhabitants by 2030 (Ministère du Plan et INS, 2023), exerts increased pressure on agricultural resources. In this context, the intensification of agriculture is essential to meet the growing food needs of a rapidly expanding population, and irrigation is a crucial component of ensuring sustainable food production (FAO, 2005).

The N'djili river basin, which encompasses surface irrigation systems, is particularly vulnerable to the challenges posed by drought. This area, with its notable hydro-agricultural potential, is experiencing climate variability that threatens the economic viability of existing irrigation systems. As highlighted by the World Bank (2023a), the assessment of economic viability of small-scale irrigation systems remains a relatively underdeveloped area of research, underscoring the necessity for more comprehensive studies in this domain. Despite its traditional use, surface irrigation may prove ineffective in the face of changing climatic conditions. It is imperative that current irrigation methods be reassessed in order to enhance their efficacy and profitability, particularly in light of the increasing prevalence of drought conditions (CIRAD, 2005). It is therefore crucial to investigate the economic impacts of drought on these systems in order to ensure food security and the economic sustainability of farmers.

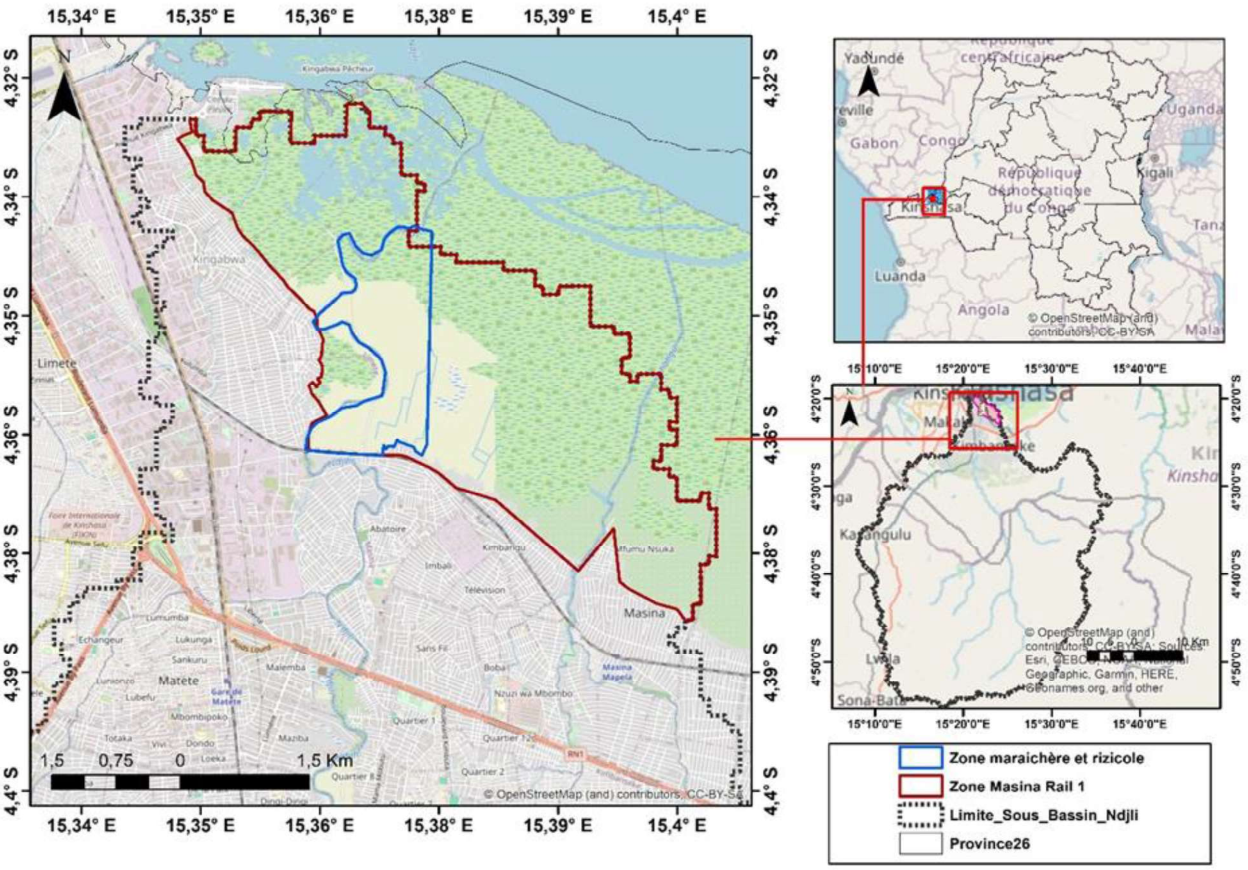
Additionally, the wetlands of the N'djili River valley, which are primarily used for rice cultivation, are susceptible to the impacts of climate change. The lack of pertinent analysis on the productivity and profitability of irrigated crops in this region constrains the capacity of farmers to adapt to environmental challenges (Baguiri, 2016). Consequently, it is imperative that research be conducted to assess the impact of drought on the profitability of irrigation systems, with a view to formulating appropriate recommendations.

The objective of this study is to provide tangible solutions to the challenges faced by producers at Masina Rail 1 in the N'djili basin in response to drought conditions. By modeling the economic impact of these conditions on surface irrigation, we aim to contribute to a more nuanced understanding of the challenges facing agriculture in the Democratic Republic of the Congo (DRC) and to propose strategies for enhancing the resilience of agricultural systems to climatic variability (Tillie et al., 2019).

MATERIALS AND METHODS

Presentation and History of the Masina Rail 1 Farming Site

The Masina Rail 1 farming site is situated within the N'djili catchment area, specifically in the Pool Malebo region. The agricultural site of Masina Rail 1 is located in the Masina commune, specifically in the Mfumu-Sunka district. It was established in 1969, coinciding with the arrival of Chinese immigrants. The site is bordered to the north by the Congo River, to the south by the railway line, to the east by the Masina Rail 2 site, and to the west by the Ngwele River, also known as the N'DJILI River. The site encompasses an area of 1,350 hectares, of which 760 hectares are under cultivation. The remaining 590 hectares are not cultivated due to a lack of irrigation infrastructure. The site is divided into 21 blocks, with an estimated 1,200 households comprising 5 to 6 individuals per household.



Sampling Methods and Techniques

Methods

The data collected for the present study were analyzed using a variety of tools and methods, including descriptive statistics, mean comparison tests, and multiple linear regression for determining determinants. The data analysis was conducted using the software packages SPSS 25 and Excel 2019.

Sampling Strategy and Sample Size

There are numerous sampling techniques. In the present study, we employed the following formula to draw our sample (Lututala, 2022):

$$n = z^2 \text{ x } p(1-p)/m^2 \qquad \text{(Equation 1)}$$

Given:
n= sample size
z= level of confidence according to the reduced normal distribution law (for a 95% level of confidence, z= 1.96; for a 99% level of confidence, z= 2.575)
p= estimated proportion of the population exhibiting the characteristic (when unknown, p= 0.5, which corresponds to the most unfavorable case, namely the greatest dispersion.
m represents the acceptable margin of error (for example, the objective is to ascertain the actual proportion to within 6% of the true value).
n is calculated using the following formula :

$$n = (1{,}96)^2 x (0{,}5)(1-0{,}5)/(0{,}6^2) \qquad \text{(Equation 2)}$$

$$\mathbf{n = 267}$$

Data Collection Techniques

The objective of the research was to gather quantitative data on production costs, selling prices, sales volumes, marital status of producers, and irrigated area size from questionnaires and interviews with small-scale gourd producers engaged in irrigation on the study site.

The survey was conducted using a pre-programmed questionnaire in Kobocollect. A total of 25 producers were surveyed in each of the 10 functional blocks, selected randomly, resulting in a total sample size of 250 producers at the time of data collection. The producers were selected at random from the entire site. In order to gain a deeper understanding of the irrigation system, visits were conducted to the water sources, irrigation canals, and production plots within the selected sample area. Additionally, observations were conducted regarding the irrigation water supply and the organization of production activities on the parcels. It should be noted that due to the absence of producers in the sampled blocks, which were already inundated, our study was conducted with a sample size of 250 producers. This represents a 94% success rate for our survey, with the remaining 17 individuals accounting for the remaining loss to the sample.

Data Analysis Techniques

The data collected for the present study were analyzed using a variety of tools and methods, including simulation analysis of profitability, descriptive statistics, mean comparison tests, and multiple linear regression for determining determinants. The data analysis was conducted using the software packages SPSS 25, Excel 2019 and MATLAB. These models employ computer software to simulate the operation of a system. Such models may be based on mathematical models, algorithms, rules, or interactions between different system components. Computer simulation models are employed in a multitude of fields, including finance, environmental science, engineering, logistics, and healthcare, among others. In the context of our study, we utilized the scenario analysis tool, specifically the scenario manager in Excel and MATLAB software, to conduct simulations of Margin profitability and the financial viability of various irrigation systems.

Simulation Analysis of Profitability

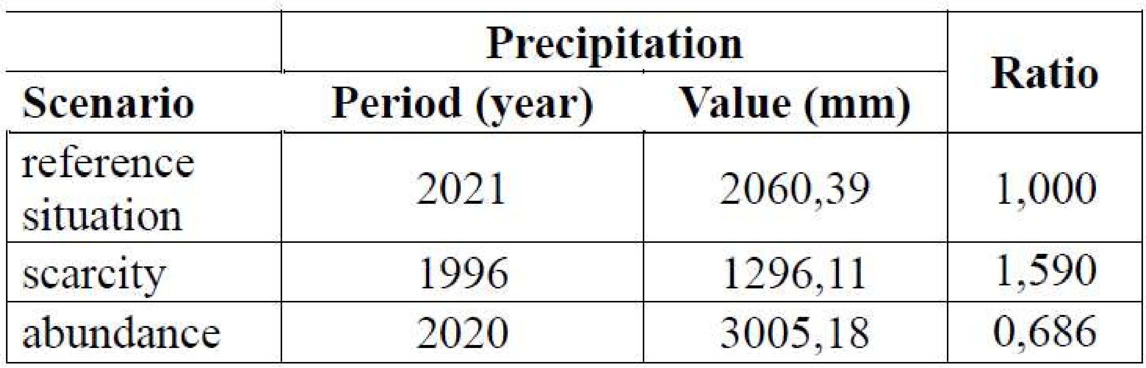
The study commenced with an assessment of climate risks to identify the impact of flooding and drought on profitability. The data on historical climatic factors was integrated with the testimonies of producers within the same conceptual framework. Subsequently, the simulation analysis involved a synthesis of price and revenue scenarios derived from rice cultivation based on the observed climatic fluctuations between 1991 and 2021.

In order to conduct simulations of periods of scarcity and abundance, a ratio was identified and applied in conjunction with the reference scenario. The ratio was identified by analyzing precipitation data from the study area from 1991 to 2021. This analysis aimed to identify the year with the highest precipitation levels and the year with the most severe drought. Our data series reveals that the year 1996, which was characterised by severe drought, and the year 2020, which was marked by The abundance of precipitation in the study area was divided by the amount of precipitation in the reference situation to obtain a ratio. The same procedure was followed for the abundance situation.

The ratio of scarcity is calculated as the precipitation in 1996 divided by the precipitation in 2021, resulting in a value of 1.590.

The ratio of abundance is calculated as the precipitation in 2020 divided by the precipitation in 2021, resulting in a value of 0.686.

Table 1. Basic scenarios for simulating prices and revenues



	Precipitation		Ratio
Scenario	Period (year)	Value (mm)	
reference situation	2021	2060,39	1,000
scarcity	1996	1296,11	1,590
abundance	2020	3005,18	0,686

In order to ascertain the sale prices and revenues for each scenario, we proceeded to multiply the ratio identified for precipitation by the sale price of the reference scenario, thereby determining the sale price in the scenario under conditions of scarcity and in conditions of abundance. This same methodology was applied to revenues and the gross margin.

The equation for revenue is R = Qté x PV,
where
R represents total revenue,
Qté denotes quantity sold,
PV signifies price of sale,
MB represents the net profit margin.
The equation for cost is CT = R-MB,
where
CT represents total cost
MB represents the net profit margin.

To conduct a sensitivity analysis, we first identified the parameters of the model that could vary. Subsequently, we established a baseline model with initial values for each parameter. Finally, we individually modified each parameter to observe the resulting changes.

The methodology for calculating sensitivity in our example is based on a comparative analysis of the net margins and profitability between the initial situation and scenarios of scarcity and abundance. Initially, the values of net margins and profitability for each sales unit in the three situations were collected. Subsequently, the variation for each unit was calculated using the following formula:

The S-value is calculated by subtracting the value in the current situation from the value in the reference situation and dividing the result by the value in the reference situation. The resulting figure is expressed as a percentage.

This allowed us to obtain variations that, when positive, indicate favourable sensitivity (an increase in the event of a shortage), while negative variations indicate unfavourable sensitivity (a decrease in the event of abundance). Furthermore, by comparing the results between the various sales units, we were able to identify those that are the most sensitive to changes in product availability, thus facilitating strategic decision-making.

Statistical analysis of profitability determinants

A multiple linear regression was employed to examine the relationships between the independent variables (costs, selling price, quantity sold, marital status, irrigated area) and the dependent variable (profitability). As posited by Kutner et al. (2004), Tabachnick & Fidell (2013), and Field (2013), the results of the regression analysis enable the relative importance of each determinant to be determined and recommendations to be formulated based on the conclusions.

Model Specification

$$\mathrm{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

$$\mathrm{MB} = \beta_0 + \beta_1 S + \beta_2 PUVR + \beta_3 QVR + \beta_4 CTR + \varepsilon$$

With :
"S" represents the perception of dryness.
"PUVR" denotes the unit price of rice.
"QVR" signifies the quantity of rice sold.
"CTR" represents the total cost of rice production.
In this equation, MB is employed to represent the probability of profitability or the net margin of the irrigation system. The regression coefficients β_o, β_(1), β_2, β_3, and β_4 quantify the impact of each independent variable on the probability of profitability. In this context, e represents the concept of random error. In order to estimate the regression coefficients, a statistical method such as the maximum likelihood method is employed. Once the coefficients have been calculated, they can be employed to analyse the influence of each independent variable on the probability of profitability of the irrigation system. The independent variables in this model include elements such as:

- Perception of drought (S)
- Unit price of rice (PUVR)
- Quantity of rice sold (QVR)
- Total cost of rice production (CTR)

Nullity test of parameters

$$\text{The critical value of } t \text{ for a one} - \text{tailed test with a significance level of } 5\% \text{ is } 1.96. \text{Therefore, the following inequalities hold}$$

$$t\beta\_0 = \beta\_0/(SE\beta\_0\ ) \geq 1.96$$
$$t\beta\_1 = \beta\_1/(SE\beta\_1\ ) \geq 1.96$$
$$t\beta\_2 = \beta\_2/(SE\beta\_2\ ) \geq 1.96$$
$$t\beta\_3 = \beta\_3/(SE\beta\_3\ ) \geq 1.96$$
$$t\beta\_4 = \beta\_4/(SE\beta\_4\ ) \geq 1.96$$

Test of Model Relevance

In order to evaluate the factors influencing the profitability of rice cultivation, we employed a multiple linear regression method. Information was gathered from a sample of producers regarding drought conditions, the price of rice per kilogram, sales volumes, and total costs. The coefficients were calculated using the ordinary least squares method, with tests of significance employed to confirm the relationships. The profitability prediction was conducted by incorporating values for each variable, and its reliability was validated through variance analysis tests, including an R2 and a Fisher test at a 5% significance level. This approach facilitated the identification of crucial factors influencing profitability, offering precise recommendations to rice producers for strategic adjustments.

The validation of the statistics pertaining to the determinants of the profitability of rice cultivation was conducted in accordance with meticulous methodological procedures. Each coefficient was examined for its impact on profitability, with significance tests indicating that all were significant at the 1%, 5%, and 10% levels. The residuals were examined for a normal distribution, and homoscedasticity was evaluated to ensure constant error variance. The issue of multicollinearity was addressed through the use of the variance inflation factor (VIF), which ensured the independence of observations. The analysis of variance (ANOVA) was employed to substantiate the relevance of the model, with an R^2 and the Fisher test (Prob > F = 0.000) indicating that the model is statistically significant. Additionally, cross-validation techniques were considered to assess the robustness of the results, thereby enhancing the credibility and applicability of the conclusions for rice producers. Furthermore, a discussion of the results enabled a comparison with similar studies in other regions to evaluate the robustness and relevance of the conclusions (Cohen et al., 2003).

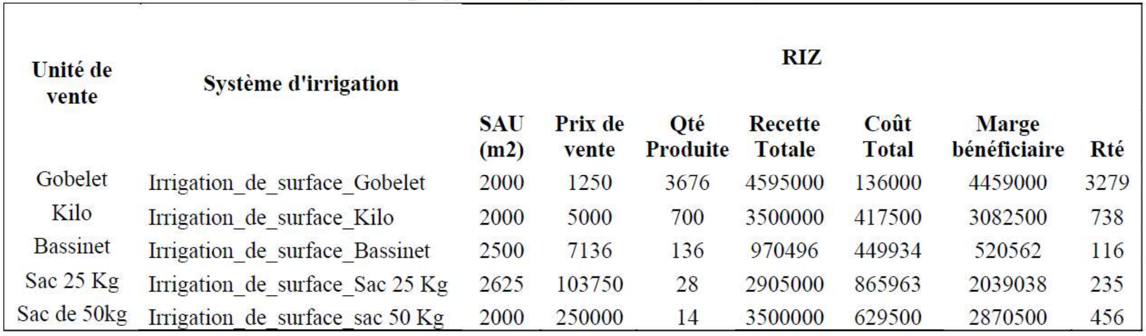
RESULTS

Analysis of profitability

Profitability of rice

With regard to the profitability of rice, the results demonstrate notable fluctuations contingent on the unit of sale and the irrigation system employed. With regard to the unit of sale comprising a 2500 m² area, the sale price is 7136, resulting in a total revenue of 970496 Fc and a net profit of 520562 Fc. This corresponds to an overall return on investment (ROI) of 116%. In contrast, the unit of sale in the form of a cup, with a surface area of 2000 m², has a sale price of 1250 Fc, yet produces a remarkable quantity of 3676. This results in a total revenue of 4595000 Fc and a net profit of 4459000 Fc, representing an extremely high rate of return of 3279%. The other selling units, such as the kilo and the 25-kilogram bag, also exhibit positive net profit margins, albeit to a lesser extent, with respective rates of return of 738% and 235%. Conversely, the 50-kilogram bag, despite an elevated selling price of 250,000 Fc, generates a net profit of 287,050 Fc, with a return on investment of 456%. These results indicate that, although certain sales units may appear less profitable in terms of margin, they may offer promising opportunities depending on production volume and cost management. This underscores the necessity for a tailored strategy for each irrigation system to achieve optimal profitability (Table 1).

Table 2 : Rice profitability by sales unit (CDF)[1]



Unité de vente	Système d'irrigation	RIZ						
		SAU (m2)	Prix de vente	Qté Produite	Recette Totale	Coût Total	Marge bénéficiaire	Rté
Gobelet	Irrigation_de_surface_Gobelet	2000	1250	3676	4595000	136000	4459000	3279
Kilo	Irrigation_de_surface_Kilo	2000	5000	700	3500000	417500	3082500	738
Bassinet	Irrigation_de_surface_Bassinet	2500	7136	136	970496	449934	520562	116
Sac 25 Kg	Irrigation_de_surface_Sac 25 Kg	2625	103750	28	2905000	865963	2039038	235
Sac de 50kg	Irrigation_de_surface_sac 50 Kg	2000	250000	14	3500000	629500	2870500	456

[1] ***Note :***
1$ = 2700 CDF

Revenue from Rice

The results of the rice price scenarios demonstrate the impact of climatic variations on producer revenues. In the baseline scenario, the selling price is stable, with a 50-kilogram bag costing 250,000 Fc, indicating a balanced profitability. In the event of a shortage, prices rise significantly, reaching 397500 Fc for the same quantity, thereby enabling producers to benefit from elevated revenues (5565000 Fc). This demonstrates that demand increases in response to limited supply. Conversely, in the scenario of abundance, prices decline to 171,500 Fc, resulting in a reduction of income to 240,100 Fc. This exemplifies the risks associated with overproduction and price depreciation. These results highlight the necessity for producers to adopt adaptive strategies in accordance with climatic conditions, with the objective of maximizing profitability while avoiding excess production.

Table 3 : Rice income scenario based on sales (CDF)[1]

Unité de vente	Système d'irrigation	Scénario de référence	Pénurie		Abondance	
		Valeur	Ratio	Valeur	Ratio	Valeur
Gobelet	PV_Irrigation_de_surface__Gobelet	1250	1,59	1988	0,686	858
Kilo	PV_Irrigation_de_surface__Kilo	5000	1,59	7950	0,686	3430
Bassinet	PV_Irrigation_de_surface__Bassinet	7136	1,59	11346	0,686	4895
Sac 25 Kg	PV_Irrigation_de_surface__Sac_25_Kg	103750	1,59	164963	0,686	71173
Sac de 50kg	PV_Irrigation_de_surface__sac_50_Kg	250000	1,59	397500	0,686	171500
Unité de vente	**Revenu du Riz**					
Gobelet	Revenu_Surf_Gobelet	4595000	1,59	7306050	0,686	3152170
Kilo	Revenu_Surface_Kilo	3500000	1,59	5565000	0,686	2401000
Bassinet	Revenu_Surf_Bassinet	970496	1,59	1543089	0,686	665760
Sac 25 Kg	Revenu_Surf_Sac_25_Kg	2905000	1,59	4618950	0,686	1992830
Sac de 50kg	Revenu_Surf_Sac_50_Kg	3500000	1,59	5565000	0,686	2401000

[1] **Note :**
1$ = 2700

Marge beneficiary of rice

The results concerning the margin beneficiaries du Riz demonstrate the considerable impact of climatic conditions on the profitability of producers. In the baseline scenario, the gross margin for a 50-kilogram bag is 287,050 Fc, indicating a favorable economic situation. In periods of scarcity, this margin increases considerably to 4564095 Fc, demonstrating that producers can benefit from an increased demand when supply is limited. However, in the scenario of abundance, the profit margin declines to 1969163 Fc due to a reduction in prices, which highlights the risks associated with overproduction. These results demonstrate that the profitability of producers is significantly influenced by fluctuations in supply and demand, and underscore the necessity of adapting production strategies to maximize profit margins in accordance with climatic conditions.

Table 4: Rice profit margin scenario (CDF)[1]

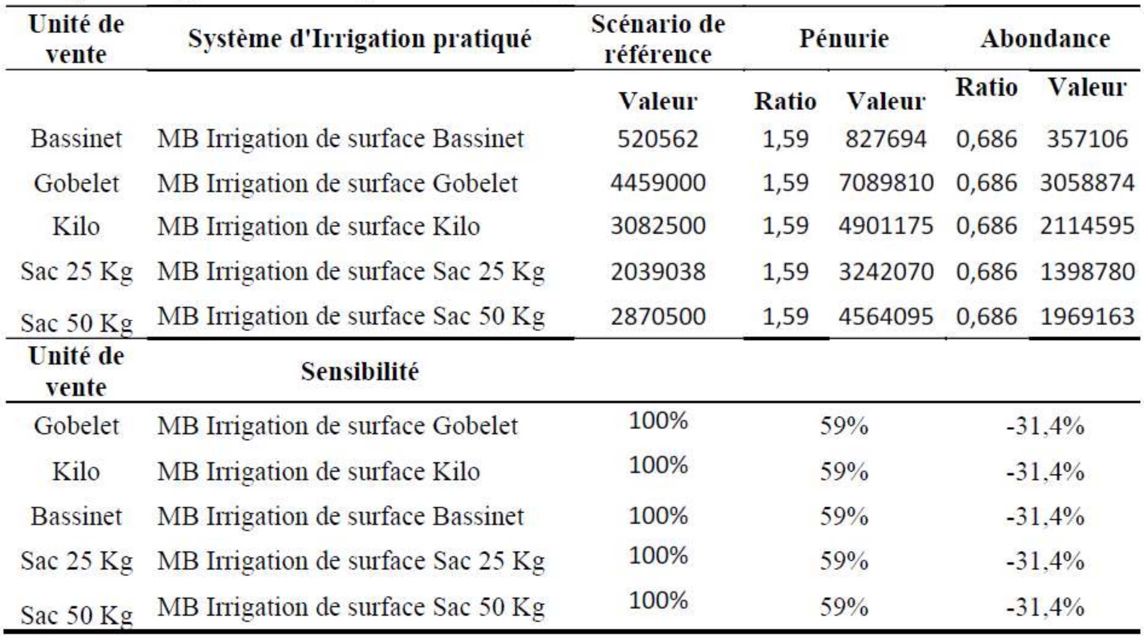
Unité de vente	Système d'Irrigation pratiqué	Scénario de référence	Pénurie		Abondance	
		Valeur	Ratio	Valeur	Ratio	Valeur
Gobelet	PV_Irrigation_de_surface__Gobelet	1250	1,59	1988	0,686	858
Kilo	PV_Irrigation_de_surface__Kilo	5000	1,59	7950	0,686	3430
Bassinet	PV_Irrigation_de_surface__Bassinet	7136	1,59	11346	0,686	4895
Sac 25 Kg	PV_Irrigation_de_surface__Sac_25_Kg	103750	1,59	164963	0,686	71173
Sac 50 Kg	PV_Irrigation_de_surface__sac_50_Kg	250000	1,59	397500	0,686	171500
Unité de vente	**Marge Bénéficiaire**					
Gobelet	MB Irrigation de surface Gobelet	4459000	1,59	7089810	0,686	3058874
Kilo	MB Irrigation de surface Kilo	3082500	1,59	4901175	0,686	2114595
Bassinet	MB Irrigation de surface Bassinet	520562	1,59	827694	0,686	357106
Sac 25 Kg	MB Irrigation de surface Sac 25 Kg	2039038	1,59	3242070	0,686	1398780
Sac 50 Kg	MB Irrigation de surface Sac 50 Kg	2870500	1,59	4564095	0,686	1969163

[1] **Note :**
1$ = 2700 CDF

Margin Benefit Sensitivity Analysis CDF

The sensitivity analysis of the profitability revealed essential interactions related to the irrigation system utilized for each sales unit. In periods of scarcity, all units, whether basins, bowls, kilograms, 25-kilogram sacks, or 50-kilogram sacks, demonstrate a significantly elevated profit margin, with a rate of 59% in comparison to normal conditions. This indicates that the implementation of surface irrigation systems enables the optimization of profits, thereby providing rice producers with the flexibility to increase prices or reduce expenditures during periods of scarcity. Conversely, in the event of abundance, all units experience a notable decline in profitability, with reductions reaching -31.4%. This negative sensitivity to abundance indicates that, despite the advantages of the irrigation system, an increase in sales volume does not offset the competitive pressure on prices. In light of these findings, it is evident that strategic irrigation resource management is of paramount importance in order to achieve the greatest profit margins in response to fluctuations in supply.

Table 5 : Profit margin sensivility scenario (%)



Unité de vente	Système d'Irrigation pratiqué	Scénario de référence	Pénurie		Abondance	
		Valeur	Ratio	Valeur	Ratio	Valeur
Bassinet	MB Irrigation de surface Bassinet	520562	1,59	827694	0,686	357106
Gobelet	MB Irrigation de surface Gobelet	4459000	1,59	7089810	0,686	3058874
Kilo	MB Irrigation de surface Kilo	3082500	1,59	4901175	0,686	2114595
Sac 25 Kg	MB Irrigation de surface Sac 25 Kg	2039038	1,59	3242070	0,686	1398780
Sac 50 Kg	MB Irrigation de surface Sac 50 Kg	2870500	1,59	4564095	0,686	1969163

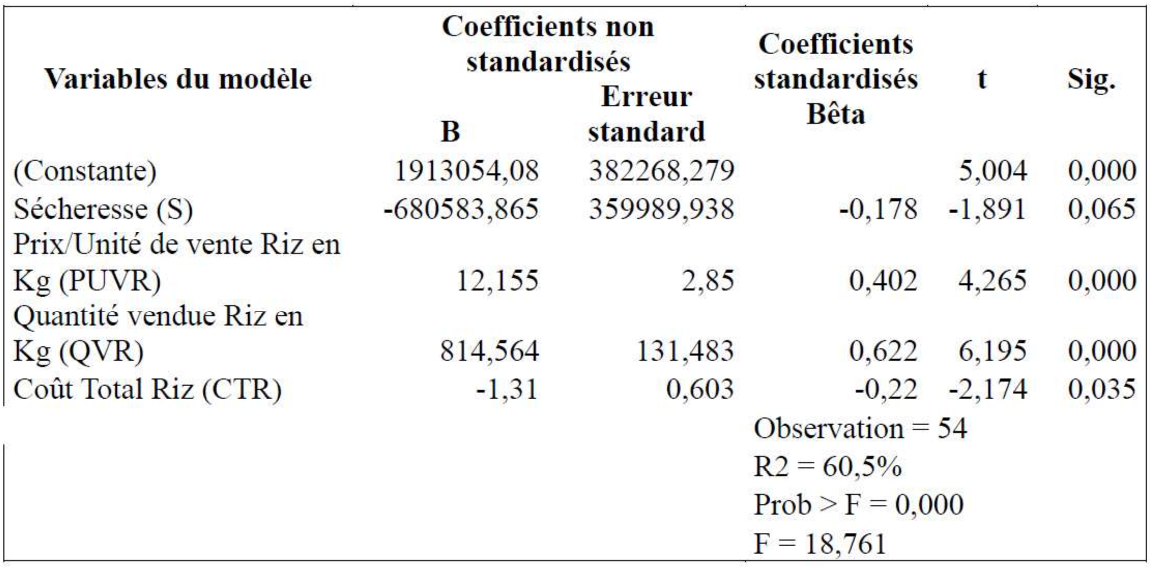
Unité de vente	Sensibilité			
Gobelet	MB Irrigation de surface Gobelet	100%	59%	-31,4%
Kilo	MB Irrigation de surface Kilo	100%	59%	-31,4%
Bassinet	MB Irrigation de surface Bassinet	100%	59%	-31,4%
Sac 25 Kg	MB Irrigation de surface Sac 25 Kg	100%	59%	-31,4%
Sac 50 Kg	MB Irrigation de surface Sac 50 Kg	100%	59%	-31,4%

[I] Note :
1$ = 2700 CDF

Determinants of Rice Cultivation Profitability in Surface Irrigation Systems

MB = 1913054,08 - 680583,865 S + 12,155 PUVR + 814,564 QVR - 1,31 CTR
(t=5,004) (t=-1,891) (t=4,265) (t=6,265) (t=-2,174)

Tableau 6 : Determinants of crop profitability



Variables du modèle	Coefficients non standardisés B	 Erreur standard	Coefficients standardisés Bêta	t	Sig.
(Constante)	1913054,08	382268,279		5,004	0,000
Sécheresse (S)	-680583,865	359989,938	-0,178	-1,891	0,065
Prix/Unité de vente Riz en Kg (PUVR)	12,155	2,85	0,402	4,265	0,000
Quantité vendue Riz en Kg (QVR)	814,564	131,483	0,622	6,195	0,000
Coût Total Riz (CTR)	-1,31	0,603	-0,22	-2,174	0,035
			Observation = 54		
			R2 = 60,5%		
			Prob > F = 0,000		
			F = 18,761		

: valeur significative à 1 % (p≤0,01) ; : valeur significative à 5 % (0,01< p≤0,05) ; : valeur significative à 10 % (0,05< p≤0,10)

The analysis of the determinants of rice reveals several significant factors influencing the profitability of rice produced and sold under surface irrigation systems. With an adjusted R^2 coefficient of 60.5%, the model explains a notable proportion of the price variance. The Fisher test (Prob > F = 0.000) indicates that the model is statistically significant at the 1% level. These results highlight the importance of monitoring these variables in order to optimize the economic performance of the rice sector at Masina Rail 1. This indicates that there are still unconsidered random or non-random factors that may explain the profitability of rice production in the area. In the variable group, the positive and significant coefficient of the rice price per unit of sale (PUVR) is 12.155, indicating that when the price per kilogram increases, the quantity sold also tends to increase, suggesting a price-elastic demand. Similarly, the quantity sold (QVR) exhibits a positive coefficient (814.564), indicating that an increase in the quantity sold results in substantial additional revenue. Conversely, the perception of drought (S) on the site has a negative impact on price, with a coefficient of -680583.865 at the 10% significance threshold (p = 0.065), indicating a tendency for decreased profitability during periods of drought. This suggests that the presence of drought on the site reduces the availability of irrigation water, thereby reducing the probability of profitability in the absence of adaptive measures. Furthermore, the total cost of production of rice (CTR) exhibits a negative coefficient (–1.31), indicating that higher expenditures result in a reduction of the profit margin, which may be attributed to lower profit margins.

DISCUSSION

The economic profitability of rice production with surface irrigation was estimated, which provided insight into the irrigation practices of small-scale rice producers in the Masina Rail 1 area of the N'djili catchment area in Kinshasa, Democratic Republic of the Congo. To perform the various scenarios, a precipitation ratio was established to calculate the selling price, revenue, and net profit in the event of water scarcity or abundance at the site. The results of the price scenario simulations demonstrate the impact of climatic variations on rice prices, producer income, and profitability. The results demonstrate that the profitability of producers is significantly influenced by fluctuations in supply and demand, emphasizing the necessity of adapting production strategies to maximize profit margins in accordance with climatic conditions. With regard to the profitability of rice, the results demonstrate notable variations contingent on the unit of sale and the irrigation system employed. The results pertaining to the profitability of rice in the study area under the reference scenario exhibited positive margins for all units of sale, irrespective of the surface irrigation system utilized in rice production. This indicates that revenue was sufficient to cover total costs. This would indicate that rice production at Masina Rail I is economically viable given the climatic conditions. These findings corroborate those of Yabi et al. (2012) and Issiaka et al. (2019), who demonstrated that rice cultivation was economically viable in terms of cost coverage in the communes of Malanville and Kouandé in Benin. The analysis of the determinants of rice revealed several significant factors influencing both the price of sale and the quantity sold. Among the variables, the price per unit of sale of rice (PUVR) has a positive and significant coefficient (12.155), indicating that an increase in the price per kilogram leads to an increase in sales volume, suggesting a demand curve that is elastic. Similarly, the quantity sold (QVR) has a positive coefficient (814.564), indicating that an increase in the quantity sold generates significant additional revenue. Conversely, the effect of drought (S) on price is negative, indicating a tendency to reduce prices during periods of drought. Moreover, the total cost of rice (CTR) also has a negative coefficient, indicating that higher costs lead to a reduction in the selling price, potentially due to lower profit margins. Empirical research has examined the factors influencing productivity, yield, and the adoption of certain practices by producers. In their study on soil and water conservation and economic performance in Benin rice production, Issiaka and colleagues (2019) demonstrated that the installation of filter ditches has a positive impact on farmers' net margins. Nevertheless, the results indicate that the cost of producing rice has a negative impact. Moreover, Niang et al. (2017) demonstrated that the construction of dikes was beneficial for improving yields in West African rice production systems. As Ouedraogo (2012) notes, the size of farming households enables farmers to meet their labor needs, which represents a significant constraint in the context of extensive agriculture. Moreover, Yabi et al. (2012) demonstrated that the majority of rice farmers in the Malanville commune were unable to repay the loans they had taken out using the income generated from this activity. Adegbola et al. (2003) demonstrated that the profitability of rice production in Benin is contingent upon the specific region under study and the production system employed. As Nuama (2006) asserts, the utilisation of a service of vulgarisation has a significant and beneficial impact on cultivated production. Similarly, the findings of Nonvide (2017) indicated that awareness-raising initiatives provide farmers with the opportunity to gain familiarity with new agricultural methods and technologies. In their study on the socioeconomic determinants of profit in southern Benin's floodplain rice production, Adegbola et al. (2023) found that rice production is more profitable than the cultivation of rice and okra. This suggests that the latter combination does not offer additional benefits to floodplain rice farmers.

CONCLUSION

This study highlighted the significant impact of climatic conditions, particularly drought, on the economic profitability of rice cultivation in surface irrigation systems at the Masina Rail I site. Simulation results reveal varying profit margins based on sales units, with exceptional performances reaching up to 3279% in some cases during periods of scarcity. Conversely, overproduction has led to a sharp decline in prices and revenues, underscoring the challenges faced by producers.

The sensitivity analysis showed that all sales units benefit from significantly higher profit margins during shortages, emphasizing the advantages of surface irrigation systems in optimizing gains when water is scarce. However, during periods of abundance, margins dropped considerably, with decreases reaching -31.4%, illustrating competitive pressure on prices. The model validation was also encouraging, with an adjusted R^2 of 60.5%, indicating that our model effectively explains a significant portion of price variance, reinforced by a statistically significant Fisher test at the 1% level.

These results highlight the importance of strategic irrigation management to maximize profits while adapting to climatic fluctuations. Factors such as price per sales unit and quantity sold play essential roles in profitability, while perceptions of drought and production costs can weigh heavily on margins. This underscores the need for producers to develop adaptive responses to ensure the economic viability of rice cultivation in the face of these challenges.

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