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TEMPORAL AND SPATIAL DYNAMICS OF IMPROVED RICE VARIETY DIFFUSION ACROSS SENEGAL'S PRODUCTION SYSTEMS

DYNAMIQUES SPATIO-TEMPORELLES DE LA DIFFUSION DES VARIÉTÉS AMÉLIORÉES DE RIZ DANS LES SYSTÈMES DE PRODUCTION SÉNÉGALAIS

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ABSTRACT

Rice self-sufficiency is a strategic priority in Sub-Saharan Africa (SSA), where the diffusion of improved rice varieties (IRVs) remains constrained by institutional and agro-ecological heterogeneity. In Senegal, the National Rice Self-Sufficiency Programme has strongly promoted IRV adoption, yet evidence remains limited on how adoption unfolds over time and how it varies spatially across contrasting production systems. Using primary survey data collected in 2026 from 474 rice producers in irrigated and rainfed systems, this study provides a descriptive assessment of IRV diffusion dynamics of Improved Rice Variety Diffusion Across Senegal's Production Systems. We combined bivariate comparisons (t-tests and χ^2) with a logistic growth model to trace the temporal adoption trajectory and identify tipping points. Spatial analysis documents adoption rates and intensity across seven regions. Results showed an overall adoption rate of 57.69%, with pronounced spatial heterogeneity: irrigated areas reach near-universal adoption (Saint-Louis 96%, Matam 95%); while rainfed regions lag significantly (Tambacounda 18.18%, Sédhiou 22.67%). Adoption dynamics followed a logistic diffusion pattern, with a tipping point around 2010-2011, coinciding with PNAR operationalisation. However, certified seed use remained low (35.83% overall), revealing a gap between varietal adoption and qualitative seed access, particularly in rainfed systems. The probit model confirmed that literacy, rice-growing area, fertiliser use, technical supervision and banking access were positively associated with adoption; while experience and total household area showed negative associations. These findings suggest that a national rice policy must shift from uniform input distribution toward geographically targeted support and seed system strengthening in lagging rainfed areas. Thus input subsidies alone are insufficient to sustain equitable diffusion without strengthening institutional support and seed systems in lagging regions.

Key Words: AImproved variety adoption, propensity score matching, rice productivity, Senegal, technology diffusion

RÉSUMÉ

L'autosuffisance en riz est une priorité stratégique en Afrique subsaharienne, où la diffusion des variétés améliorées de riz demeure freinée par l'hétérogénéité institutionnelle et agroécologique. Au Sénégal, le Programme national d'autosuffisance en riz a fortement encouragé l'adoption des variétés améliorées de riz, mais les données restent limitées quant à la manière dont cette adoption se déroule dans le temps et varie spatialement selon les différents systèmes de production. À partir de données d'enquête primaires recueillies en 2026 auprès de 474 riziculteurs en systèmes irrigués et pluviaux, cette étude propose une évaluation descriptive de la dynamique de diffusion des variétés dans les systèmes de production sénégalais. Nous avons combiné des comparaisons bivariées (tests t et χ^2) avec un modèle de croissance logistique pour retracer la trajectoire temporelle de l'adoption et identifier les points de basculement. L'analyse spatiale documente les taux et l'intensité d'adoption dans sept régions. Les résultats ont montré un taux d'adoption global de 57,69 %, avec une forte hétérogénéité spatiale : les zones irriguées atteignent une adoption quasi universelle (Saint-Louis : 96 %, Matam : 95 %), tandis que les régions pluviales accusent un retard significatif (Tambacounda : 18,18 %, Sédhiou : 22,67 %). La dynamique d'adoption a suivi un modèle de diffusion logistique, avec un point d'inflexion autour de 2010-2011, coïncidant avec la mise en œuvre du PNAR. Cependant, l'utilisation de semences certifiées est restée faible (35,83 % au total), révélant un écart entre l'adoption variétale et l'accès à des semences certifiées , en particulier dans le système pluvial du Sud. Le modèle probit a confirmé que l'alphabétisation, la superficie rizicole, l'utilisation d'engrais, la supervision technique et l'accès aux services bancaires étaient positivement associés à l'adoption ; tandis que l'expérience et la superficie totale du ménage présentaient des associations négatives. Ces résultats suggèrent qu'une politique nationale rizicole doit évoluer d'une distribution différenciée des intrants vers un soutien ciblé géographiquement et un renforcement du système semencier dans les zones pluviales en retard. Ainsi, les subventions aux intrants à elles seules ne suffisent pas à assurer une diffusion équitable sans renforcer le soutien institutionnel et le dispositif semencier dans les régions en retard de développement.

Mots Clés : Adoption de variétés améliorées , appariement par score de propension , riz productivité agricole, Sénégal , diffusion technologique

INTRODUCTION

Rice is the staple food in Senegal, with per *capita* consumption reaching approximately 120 kg per year, one of the highest levels in West Africa (USDA, 2025). Driven by rapid population growth and urbanisation, domestic demand continues to rise; yet local production still covers less than 45% of national needs, forcing the country to import approximately 1.6 million tonnes annually at a cost exceeding USD 564 million (USDA, 2025). Closing this gap is a strategic imperative, and the dissemination of improved rice varieties (IRVs) developed by AfricaRice and ISRA; and offering higher yields, stress tolerance, and shorter cropping cycles represents a central lever for national rice productivity (Faye *et al*., 2021; Moukoumbi *et al.,* 2025). Yet, despite three decades of varietal releases and substantial public investment, the diffusion of these technologies across Senegal's diverse production systems remains poorly understood.

The diffusion of agricultural innovations has been a central topic in development economics since the seminal work of Griliches (1957) on hybrid maize; and Feder *et al*. (1985) on the determinants of technology adoption among farmers. In the empirical literature, two complementary indicators are commonly used: the adoption rate (the proportion of producers cultivating at least one IRV) and the adoption intensity (the share of cultivated area allocated to IRVs), with the latter capturing the depth of technology uptake that binary measures miss (Arouna *et al*., 2017; Diagne *et al*., 2017).

In sub-Saharan Africa, the adoption of improved rice varieties has attracted growing attention, particularly after the 2008 global food crisis, which catalysed regional investment in the rice sector. Arouna *et al*. (2017), using data from sixteen countries, demonstrated that IRV adoption significantly improved food security and poverty reduction over 2000–2014, lifting approximately eight million people out of poverty. However, the same authors noted that adoption rates and intensity remained heterogeneous, constrained by access to certified seeds, extension services, and financial liquidity. More recently, studies have confirmed that the determinants of adoption extend beyond individual farm characteristics to include institutional factors: subsidy regimes, seed system governance, and market access (Wossen *et al*., 2017; Liverpool-Tasie *et al*., 2020). Fisher *et al*. (2025) further emphasised that the quest for food sovereignty in Africa adds a political dimension to adoption dynamics, as governments use production targets as instruments of legitimacy.

In the West African rice sector, the dissemination of IRVs has been led by AfricaRice and national research partners, resulting in the registration of approximately 570 varieties across the top ten producing countries by 2020 (Futakuchi and Saito, 2021). In Senegal specifically, 45 varieties have been released since the 1994, spanning irrigated, lowland and rainfed ecosystems, yet field evidence shows that a handful of Sahel varieties dominate the irrigated Senegal River Valley; while rainfed systems in Casamance and the eastern regions remain on the margins of varietal modernisation (Faye *et al*., 2021; Futakuchi *et al*., 2021).

This structural divide between irrigated and rainfed systems is central to understanding diffusion patterns. Irrigated systems, concentrated in the Senegal River Valley (Saint-Louis and Matam), benefit from controlled water access, proximity to seed multiplication centres, and stronger institutional infrastructure, creating an environment highly conducive to IRV adoption. Rainfed systems, predominant in the southern and eastern regions (Ziguinchor, Kolda, Sedhiou, Kédougou and Tambacounda), face climatic vulnerability, fragmented land tenure, and weaker access to input. Additionally, markets conditions systematically limit both the adoption rate and the intensity of use (Takahashi *et al*., 2020; Loko *et al*., 2022). Yet, most existing adoption studies in Senegal focus predominantly on the Valley and treat adoption as a binary outcome, without examining how diffusion dynamics unfold over time or how intensity varies across these structurally distinct production systems.

Public policy has played a central role in shaping the adoption landscape. Since 2008, the Senegalese government has launched successive programmes (the GOANA initiative, the PNAR, and PRACAS) mobilising substantial investments in input subsidies, certified seed distribution, and irrigation infrastructure (Seck *et al*., 2015; Diallo, 2022). More recently, the revised National Rice Development Strategy (NRDS II 2026-2030) targets rice self-sufficiency by 2030 through a production goal of 3 million tons of paddy rice. However, literature consistently warns that subsidy-based policies improve initial access to technology, but do not guarantee sustained, intensive adoption in the absence of efficient seed systems and effective extension services (Jayne *et al*., 2018). In Senegal, certified seed availability remains structurally constrained, and the institutional coordination needed to bridge the gap between research outputs and farmer uptake is still incomplete (Soullier *et al*., 2020).

Against this background, three specific gaps emerge in the literature ; namely, first, most studies in Senegal adopt a static, binary approach to adoption (adopter vs. non-adopter) without analysing the temporal dynamics of diffusion, that is, when adoption accelerated, whether the system has reached a tipping point, and in what phase of diffusion it currently stands. Secondly, studies that do examine adoption across regions rarely combine adoption rates, intensity of use, and

production system heterogeneity within a unified spatial framework, limiting the ability to identify where diffusion is lagging and why. Thirdly, the policy implications of adoption studies are often stated in general terms, without specifically connecting empirical findings to the design of national programs such as the PNAR or the NRDS II.

This study addresses these gaps using primary data collected in 2026 from 474 rice producers distributed across Senegal's main production systems. We pursue three objectives: (1) to characterise the socio-economic profiles of rice producers and their access to support services across production systems; (2) to trace the temporal adoption trajectory of IRVs using a logistic growth model, identify the tipping point, and classify producers into adoption typologies; and (3) to assess spatial disparities in adoption intensity and certified seed use between irrigated and rainfed systems, and to discuss the alignment between observed diffusion patterns and national rice policy objectives. To achieve this, we employ a dual-frame stratified sampling design, analyse adoption at both the household and plot levels, model temporal diffusion using a logistic growth function, and estimate a probit model to identify factors associated with adoption. By integrating temporal trajectories, spatial disparities, and institutional constraints, this study provides a comprehensive, policy-relevant assessment of IRV diffusion and offers targeted evidence to align Senegal's rice development strategy with on-the-ground adoption realities.

METHODOLOGY

Study area. The study was conducted in the main rice-growing areas of Senegal, including the Senegal River Valley, Casamance, eastern Senegal, and the Groundnut Basin. These areas were chosen because of their importance to rice production and the presence of diverse seed producers.

The irrigated system comprising the Senegal River Basin (Saint-Louis, Matam) and the Anambé Basin provides on average 27% of the national paddy rice production (DAPSA, 2023). The rainfed system, comprising the Groundnut Basin regions (mainly Fatick, Kaolack, and Kaffrine), and the regions of Kolda, Ziguinchor, Sédhiou, Tambacounda, and Kédougou, contributes 73% of the national paddy rice production (DAPSA, 2023).

Data collection. The sampling method was based on Fisher's approach (Fisher *et al.*, 1998), commonly used in agricultural surveys when the size of the parent population is known. This method allows for the determination of a statistically representative sample size based on the confidence level, the margin of error, and the expected variability of the phenomenon under study. The theoretical sample size is determined using the following relationship:

$$n = \frac{Z^2 x\, p(1-p)}{e^2}$$

Where:

(n) represents the theoretical sample size,
(Z) the value of the normal distribution associated with the chosen confidence level (1.96 for a 95% threshold),
(p) the estimated proportion of the population exhibiting the studied characteristic (set at 0.5 to maximise variance and ensure a conservative sample), and
(e) the margin of error allowed (generally set at 5%).

Given that the population of rice-farming households is finite and known from the sampling frames of DAPSA (rainfed areas) and SAED (irrigated areas), a correction for a finite population is applied according to the following formula:

$$nf = \frac{n}{1 + \frac{n}{N}}$$

Where :

(nf) is the final sample size and (N) is the total number of rice-farming households surveyed.

Applying this correction results in a sample of 305 households in rainfed areas and 169 farms in irrigated areas, for a total of 474 observations units. The spatial distribution of the sample is based on an allocation proportional to the agricultural weight of the regions, measured using rice production statistics from the DAPSA for the 2025 season. The weight of each region is defined as follows:

$$Poids_i = \frac{Production_i}{Total\ production}$$

In a two-stage cluster sampling approach, the village (or PIV) constitutes the primary sampling unit. Following the recommendations of Cochran (1977) and Kish (1965), a limited number of units per cluster reduces the effect of within-group correlation while ensuring the accuracy of the estimates. To this end, 12 producers were surveyed per village or development area, a threshold consistent with agricultural survey standards (FAO, 2014).

The distribution of the number of villages by region is described in Table 1. After presenting the research objectives to the farmers, data were collected using a KoboCollect questionnaire covering: the sociodemographic and economic characteristics of each rice farmer interviewed (age, sex, education level, years of experience in rice farming, rice farming training, household size, source of income and membership in a farmers' association); the rice production system; farming practices (cultivated area, number of plots, rice varieties cultivated, bird control, fertiliser application, type of labour, production, etc.); and production constraints.

TABLE 1. Weight of regions and number of paddy rice producers to be investigated

Area	Administrative entity	Number of respondents
	Kolda (Bayoungou, Medina Silly, Saré Mory, Saré Boydo, Touba Sadou ,Saré Ousmane, Soukou, Anambé-Secteur A, Anambé-Secteur B)	102
	Tambacounda (Sinthiou Malem)	12
	Ziguinchor (Essyl, Mlomp, Tenghori, Affiniam, Djibelor, Cabrousse)	77
	Kédougou (Afia Pont)	12
	Sédhiou (Bona, Ndiama, Birkama, Thiar Djimassar, Dianan Bah, Bambaly, Oudoucar, Manguir)	102
Sub-total		305
Irrigated Area (SAED)	Dagana (Piv de mbagam, Piv gie thiagar, Piv gie guilaado, Piv de kheune, Piv foyer thiagar, Piv guidakhar, Piv sv lougue demisse, Piv de kheune, Piv mbolom diam, Piv gie guilaado)	102
	Lac de Guiers (PIV Mbane)	8
	Podor (Piv Fanaye, Piv Ndiayenne Pendao)	23
	Matam (Matam, Sinthiou Mogo, Tiguere)	36
Sub-total		169
Total		474

The data collected during the surveys were analysed using descriptive and multivariate statistics. Data relating to the sociodemographic profile of the rice farmers interviewed and the characteristics of the farms were subjected to Pearson's Chi-squared test and t-test using the R statistical software (2026.01.2+418) to compare the different study areas. The significance level was set at $P<0.05$ and the means were compared using Student's t-test.

Analytical framework

Definition and measurement of variables. This study aims to establish what drives the adoption of improved rice varieties in Senegal. The conceptual framework is based on the theory of agricultural technology adoption (Feder *et al*., 1985; Foster and Rosenzweig, 2010) and distinguishes three sets of variables: the treatment variable (adoption), the outcome variable (yield), and the determinants of adoption and productivity.

The Adoption variable is defined as a binary variable :

$$\text{Adoption}_i = \begin{cases} 1 & \text{if the farm cultivates at least one improved variety} \\ 0 & \text{if not} \end{cases}$$

Improved varieties include cultivars listed in the Senegalese national seed catalogue, developed by ISRA and AfricaRice (ISRIZ, Sahel 108, Sahel 134, Sahel 201, Sahel 317, NERICA, etc.) (Table 2) (Demont *et al*., 2013; AfricaRice, 2022).

Rice yield, measured in kilogrammes of paddy per hectare, is the outcome variable of interest.

$$\text{Yield}_i = \frac{\text{Total paddy production (kg)}_i}{\text{Rice growing area (ha)}_i}$$

Yields are Winsorised at the 1st and 99th percentiles to limit the influence of outliers and measurement errors (Sheahan and Barrett, 2017). The determinants of adoption and productivity are grouped into four categories, in accordance with the empirical literature on technology adoption in sub-Saharan Africa (Kassie *et al*., 2015; Wainaina *et al*., 2016): (i) Farm characteristics, (ii) Household characteristics, (iii) Access to services, and (iv) Agroecological context. Table 3 summarises these variables, their measurements, and expected theoretical relationships with adoption.

The primary unit of observation in this study was the rice plot. The 474 farmers surveyed cultivate a total of 834 rice plots, which constitute the analytical sample for the analysis of adoption intensity. A single farmer cultivate one or more plots, some with improved varieties and others with traditional varieties. This approach allowed us to measure not only binary adoption at the household level, but also adoption intensity at the plot level, in accordance with recommendations in literature on measuring technology adoption.

Data analysis

(a) Descriptive statistics. Descriptive statistics constituted an essential first step in the analysis of the adoption of agricultural innovations. They were used to characterise the socio-economic profile of producers, to estimate the adoption rate of improved varieties and to measure the intensity of use from indicators of central tendency (mean, median) and dispersion (standard deviation) (Wooldridge, 2010).

(b) Comparison tests (t-test, χ^2). Statistical tests comparing means and proportions were used to identify significant differences between adopters and non-adopters. The independent samples t-test was used to compare the means of quantitative variables (e.g., age, cultivated area and yield). It allowed us to test the null hypothesis of equal means between the two groups (Student, 1908). This test is widely

TABLE 2. Rice varieties approved in Senegal since 1994 to date

Year	Ecosystem	Varieties	Cycle (days)	Yield (t ha^{-1})
1994	Irrigated	Sahel 108; Sahel 201; Sahel 202; I Kong Pao; IR1529-68O-3; IR8(-2883); JAYA; KH998; Kwang She Shung; IR442	105-120	7-8,5
1994	Lowland	DJ684D; DJ11-509; DJ12-519	100-120	4,5-5,5
1994	Plain	IRAT10; DJ8-341	100	4-5,5
1995	Irrigated	Sahel 317	122	7,5
1997	Irrigated	Sahel 222; Sahel 328**; Sahel 329**; NERICA-S-19; NERICA-S-21	103-116	6,5-7,5
1997	Lowland	TOX728-1; WAR1; WAR77-3-2-2; WAR81-2-1-3-2; ROK5; BR51-46-5; BG90-2; BW248-1; ITA123	105-125	3-8
1998	Irrigated	Sahel177**; NERICA-S-36; NERICA-S-44	122	7,5
2007	Irrigated	Sahel134; Sahel159; Sahel208; Sahel209; Sahel210	109-125	7,5-8
2009	Irrigated	Sahel217; Sahel305	120-124	8
2009	Plain	ITA150; WAB56-50; NERICA1; NERICA5; NERICA6	90-110	4-5
2017	Irrigated	ISRIZ01**; ISRIZ02**; ISRIZ03**; ISRIZ04; ISRIZ05; ISRIZ06; ISRIZ07**; ISRIZ08**; ISRIZ09H**; ISRIZ10; ISRIZ11; ISRIZ12; ISRIZ13; ISRIZ14; ISRIZ15	90-122	7-9

Notes: ** = aromatic varieties Source: Faye *et al.* (2021)

TABLE 3. Definition of variables and expected signs

Variables/Characteristics	Définition	Measure	Expected sign
Dependent variable			
Adoption of improved rice varieties	Adoption of an improved variety of rice	1 if the farmer adopts, 0 otherwise	N/A
Yield	Kg paddy ha^{-1}	-	-
Independent variables			
Socio-demographic factors			
Gender of the head of household	Gender of the head of household	1 if male, 0 otherwise	+ / -
Age of the head of household	Number of years since birth	Number	+ / -
Literacy	Ability to write and read in French	1 if he can, 0 otherwise	+
Household size	Number of household members	Number	+ / -
Rice farming experience	Years of experience in rice farming	Number	+
Marital status	Marriage	1=Married, 0=Otherwise (Single, Divorced, Widowed).	+ / -
Factors related to agricultural resources			
Ownership of machines	Ownership of agricultural equipment (tractors and towed equipment)	1 if yes, 0 otherwise	+
Total area under cultivation	Total farm size	Hectares	+
Rice-growing area	Area dedicated to rice	Hectares	+
Family labour	Use of family labour	1 if yes, 0 otherwise	+
Salaried workforce	Use of external workers	1 if yes, 0 otherwise	+
Management factors			
Crop diversification	Culture of other speculations	1 if yes, 0 otherwise	“
Rice cultivation training	Technical training received	1 if yes, 0 otherwise	+
Belonging to an organisation	Member of a farmers’ organisation	1 if yes, 0 otherwise	+
Use of fertilisers	Use of chemical inputs	1 if yes, 0 otherwise	+
Use of pesticides	Use of plant protection products	1 if yes, 0 otherwise	+
Rice production	Quantity of rice produced	Metric tonnes	+
Geographic factors			
Northern region	Irrigation system	1 if yes, 0 otherwise	+ / -
Southern region	Rainwater system	1 if yes, 0 otherwise	+ / -

used in agricultural adoption studies to analyse structural differences between producer categories (Ogada *et al*., 2014).

For qualitative variables (gender, access to credit, access to extension services and use of certified seeds), the Chi-square (χ^2) test was applied to examine the existence of a significant association between adoption status and categorical characteristics (Pearson, 1900). This test is appropriate for analysing relationships between discrete variables in agricultural surveys (Agresti, 2013).

(c) Spatial analysis. Spatial analysis aims to examine the geographic distribution of the adoption of improved varieties across the different rice-growing areas of Senegal. It is based on calculating adoption rates and average intensity per region or production system (irrigated vs. rainfed), supplemented by inter-zone comparison.

This approach is justified by the fact that the diffusion of agricultural innovations is strongly influenced by agro-ecological conditions, access to infrastructure, and territorially based public policies (Rogers, 2003). In the rice-growing context, spatial disparities are often linked to the availability of irrigation, seed systems, and regional public investments.

Spatial analysis, thus makes it possible to identify areas of high and low diffusion, helping to shed light on the challenges of territorial equity in agricultural policies.

(d) Dynamic analysis. Dynamic analysis aims to trace the temporal evolution of the adoption of improved varieties. It relies on the year of adoption reported by producers or on aggregated longitudinal data to construct a cumulative diffusion curve.

In accordance with the diffusion of innovations theory (Rogers, 2003), technological adoption generally followed an S-shaped trajectory, characterised by a slow initial phase (innovators), a rapid expansion phase (early and late majority), and then a saturation phase. The formulation corresponds to a logistical growth function of technological diffusion:

$$\text{Adoption}_t = \frac{K}{1 + e^{-b(t-t_0)}}$$

Where:

Adoption, represents the level of adoption at time t; K is the saturation level of adoption (theoretical maximum adoption); b represents the speed or diffusion rate of adoption; t_0 corresponds to the inflection point of the curve, that is, the tipping point where adoption begins to grow rapidly; and *e* is Euler's exponential constant $e \approx 2.718$.

(e) Probit Adoption Model. Examining this dynamic allowed us to assess the current stage of diffusion of improved varieties in Senegal and to determine whether the observed trajectory was consistent with national rice self-sufficiency objectives. This approach is commonly used in the analysis of agricultural diffusion processes (Feder *et al*., 1985).

To complement the descriptive and bivariate analysis, a binary probit model was estimated to identify factors significantly associated with the adoption of improved rice varieties. This type of model is commonly used in empirical studies on the adoption of agricultural technologies in sub-Saharan Africa (Feder *et al*., 1985; Kassie *et al*., 2015; Wainaina *et al*., 2016).

The dependent variable is binary and takes the value 1 if the plot is cultivated with at least one improved variety listed in the Senegalese national seed catalog, and 0 otherwise. The unit of observation is the rice plot. The model is specified as follows:

$$\Pr(Y_i = 1 \mid X_i) = \Phi(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + ... + \beta_K X_{Ki})$$

Where:

$\Pr(Y_i = 1 \mid X_i)$ represents the probability that individual iii adopts the innovation (or exhibits

the studied characteristic) given their characteristics X_i;

Φ (.) denotes the cumulative distribution function of the standard normal distribution;

β_0 is the constant;

$\beta_1, \beta_2, ..., \beta_\kappa$ are the parameters to be estimated;

$X_{1i}, X_{2i},..X_{ki}$ represent the explanatory variables.

This model aims to identify robust statistical associations between the explanatory variables and adoption probability, not to establish strict causal relationships. In the absence of a causal identification strategy, the results should be interpreted with caution, particularly for institutional variables such as access to technical guidance, subsidies, and financial services, which may be affected by selection bias or endogeneity. This limitation is discussed in the Discussion section.

RESULTS AND DISCUSSION

Socio-economic characteristics. The combined analysis of Tables 4 and 5 provides an integrated understanding of the differences between adopters and non-adopters, by linking institutional, productive, and socioeconomic dimensions. Table 4 highlights significant disparities in access to inputs, services, and financial resources; while Table 5 reveals marked differences in factor endowments and agricultural performance. Their correlations shows that these disparities are not independent, but stem from a coherent structuring of production systems.

The observed differences in input use are directly reflected in the differences in cultivated areas and quantities of seeds used. Fertiliser use was reported by 64.94% of adopters compared to 44.57% of non-adopters; while access to fertiliser subsidies reaches 92.68% among adopters versus 64.42% among non-adopters. These differences are directly related to the data in Table 4: adopters cultivateed larger plot areas (1.37 ha vs. 0.76 ha), dedicated more land to rice (2.53 ha vs. 1.25 ha), and used higher quantities of seed (90.64 kg vs. 65.30 kg). This correlation between access to inputs (Table 4) and productive capacity (Table 5) suggests that adoption is part of a broader agricultural intensification process, and not simply a matter of varietal substitution, as highlighted by Arouna *et al*. (2021) in their analysis of the adoption of improved rice varieties in West Africa. The significant yield difference observed between the two groups ; 3,775.86 kg ha^{-1} for adopters versus 1,488.11 kg ha^{-1} for non-adopters, a difference of 2,287.75 kg ha^{-1}, fits within this framework; namely the superior performance of adopters appears inextricably linked to a combination of favourable conditions. These results corroborate the findings of Wossen *et al*. (2017), who emphasised that technological adoption in SSA is generally accompanied by the combined use of complementary inputs in the form of a technology package. The marked difference in technical support and training reinforces this interpretation. Access to support was available to 76.83% of adopters compared to only 22.47% of non-adopters. This asymmetry partially explains the observed differences in farming practices and yields. The significantly higher yields observed among adopters cannot be interpreted in isolation from their improved access to information, producer organisations, and public support mechanisms. Thus, the statistical differences shown in Table 5 extend those of Table 4, revealing an accumulation of structural advantages rather than a purely technical effect of the improved variety. This finding aligns with recent work by Liverpool-Tasie *et al*. (2020) and Lecoutere *et al*. (2019), which emphasised the central role of extension services in the dissemination of agricultural innovations in Africa. However, it is important to note, in line with the findings of Abate *et al*. (2018), that direct yield comparisons generally

TABLE 4. Summary statistics for dummy variables used in this study

Variable	Adopters	Non_adopters	Mean	Difference (pp)	χ^2
Fertiliser Input on Plot	64.94% (2.63)	44.57% (3.04)	55.8% (2.04)	20.37pp	25.68***
Fertilizer Subsidy	92.68% (1.44)	64.42% (2.93)	80% (1.64)	28.26pp	96.04***
Phytosanitary Input	35.67% (2.64)	24.72% (2.64)	30.76% (1.89)	10.95pp	17.12***
Bird Attack	64.63% (2.64)	70.79% (2.78)	67.39% (1.92)	-6.15pp	4.87
Red Rice	40.55% (2.71)	77.53% (2.55)	57.14% (2.03)	-36.98pp	187.21***
Gender	73.48% (2.44)	34.08% (2.9)	55.8% (2.04)	39.39pp	183.92***
Literacy	32.93% (2.59)	13.86% (2.11)	24.37% (1.76)	19.07pp	54.08***
Marital Status	99.7% (0.3)	97.38% (0.98)	98.66% (0.47)	2.32pp	5.57**
Training	59.76% (2.71)	13.11% (2.07)	38.82% (2)	46.65pp	296.41***
Organization	81.71% (2.13)	57.68% (3.02)	70.92% (1.86)	24.03pp	63.61***
Banking Access	50.91% (2.76)	14.23% (2.14)	34.45% (1.95)	36.68pp	181.25***
Credit access	25.61% (2.41)	20.97% (2.49)	23.53% (1.74)	4.64pp	3.47
Diversification	21.04% (2.25)	32.21% (2.86)	26.05% (1.8)	-11.17pp	15.22**
Technical supervision	76.83% (2.33)	22.47% (2.55)	52.44% (2.05)	54.36pp	460.84***
Family Labor	99.39% (0.43)	100% (0)	99.66% (0.24)	-0.61pp	2.02
Wage Labor	65.54% (2.91)	55.79% (2.74)	60.17% (2.01)	9.75pp	12.67***
Mechanization (small equipment)	28.05% (2.48)	38.2% (2.97)	32.61% (1.92)	-10.15pp	11.75**

Differences are expressed as percentage points, with standard errors in parentheses. Significance levels are derived from Pearson's chi-squared test. ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively

TABLE 5. Summary statistics for continuous variables use in this study

Variable	Adopters	Non_adopers	Mean	Difference_T-test
Plot area	1.37 (0.09)	0.76 (0.04)	1.1 (0.05)	0.61 (0.09)***
Quantity of seeds	90.64 (8.75)	65.3 (7.52)	79.27 (5.91)	25.34 (11.54)**
Plot yield	3775.86 (156.83)	1488.11 (178.66)	2749.25 (126.72)	2287.75 (237.73)***
Age	49.6 (0.65)	49.4 (0.74)	49.51 (0.49)	0.2 (0.99)
Experience	20.3 (0.75)	27.84 (0.86)	23.69 (0.59)	-7.54 (1.14)***
Household's area	3.3 (0.28)	2.39 (0.2)	2.89 (0.18)	0.91 (0.35)***
Area dedicated to rice	2.53 (0.23)	1.25 (0.07)	1.96 (0.13)	1.28 (0.24)***
Household size	15.16 (0.49)	18.46 (0.66)	16.64 (0.4)	-3.3 (0.82)***
Family labour	10.5 (0.35)	12.26 (0.41)	11.29 (0.27)	-1.76 (0.54)***
Seed cost (kg)	328.16 (6.45)	138.26 (5.49)	287.82 (4.7)	189.91 (8.47)***

Standard errors are in parentheses. Significance levels are derived from the independent samples t-test

overestimate the impact of technologies due to selection bias, as adopters also benefit from better starting conditions.

Financial variables also illustrate this consistency. While access to formal credit did not significantly distinguish the two groups (a non-significant difference of 4.64 percentage points), banking penetration appeared strongly differentiated in favour of adopters, with 50.91% of them having access compared to only 14.23% of non-adopters (a difference of 36.68 percentage points). This greater financial inclusion is combined with increased use of inputs and larger cultivated areas; suggesting a higher investment capacity. The productivity gaps highlighted in Table 5, particularly in terms of cultivated area and seed quantities, then become meaningful in light of the inequalities in financial integration observed in Table 4.

These results are consistent with the analyses of Wossen *et al*. (2017) and Issahaku and Abdulai (2020), which show that financial inclusion, beyond access to credit alone, was a major determinant of technological adoption in agriculture.

From a socio-demographic perspective, adopters had a higher literacy level and were predominantly male; while non-adopters had significantly longer agricultural experience (a difference of -7.54 years), larger household sizes (a difference of -3.3 people), and a larger family labour force (a difference of -1.76 workers). Comparing these factors suggests the existence of two relatively distinct profiles. On the one hand, there are more capitalised farms, better integrated into institutional structures, and utilising more inputs; on the other hand, there are farms relying more heavily on family labor and accumulated experience. The differences in yield (2,287.75 kg ha^{-1}) and area (0.61 ha for the plot, 1.28 ha for rice paddies) observed in Table 5 further illustrate this structural distinction. The yield difference observed between plots cultivated with improved varieties (3,776 kg ha^{-1}) and those cultivated with traditional varieties (1,488 kg ha^{-1}) should be interpreted with caution. This difference reflects not only the genetic potential of the varieties, but also structural differences between production systems; including water management in irrigated areas, access to subsidised inputs, the level of mechanisation, and the intensity of technical support. A rigorous estimation of the specific effect of the variety on yield would require a counterfactual approach that is beyond the scope of this study.These inequalities in access to agricultural innovations related to gender and human capital are well documented in recent literature (Peterman *et al*., 2014; Doss *et al*.,

2018; Quisumbing *et al*., 2021). The relatively advanced age of producers across the sample is also a cross-cutting factor that spans both groups, echoing the concerns raised by Malkov *et al*. (2022) regarding the aging of the agricultural population in sub-Saharan Africa.

Finally, certain variables allowed for a more nuanced interpretation. The absence of a significant difference in bird attacks (a difference of -6.15 percentage points, not significant) and the use of family labour (a difference of -0.61 percentage points, not significant) indicates that some constraints are shared regardless of adoption status. Conversely, the presence of red rice is significantly higher among non-adopters, affecting 77.53% of them compared to 40.55% of adopters (a difference of -36.98 percentage points). This differentiating agronomic marker resonates with their lower production performance and may reflect less technical expertise or limited access to certified seeds, as observed by Rodenburg *et al*. (2019) in their work on the constraints related to red rice in West Africa.

Overall, a cross-analysis of the two tables shows that the differences between adopters and non-adopters are not limited to the use of an improved variety. They reflect a coherent set of disparities in terms of access to resources, institutional integration, endowment of production factors, and agricultural outcomes. Adoption thus appears to be associated with a specific structural configuration of the operating system, which invites us to interpret performance gaps with caution and to place them in a broader framework of differentiation of productive conditions, in accordance with recent methodological recommendations for impact assessment of agricultural technologies (Wossen *et al*., 2017; Liverpool-Tasie *et al*., 2020).

Based on statistical criteria (BIC, LR test) and the principle of parsimony, the reduced model is the most appropriate choice for estimating the propensity scores of Senegalese rice farmers. The final specification includes twelve explanatory variables: the age of the head of household, gender, literacy, household size, rice farming experience, mechanisation, rice-growing area, technical training, membership in a farmers' organisation, use of chemical fertilisers, access to technical support, and banking services access.

The Probit model (Table 6) identified the statistical variables associated with the adoption of improved varieties. It is important to clarify from the outset that this analysis aims only to highlight conditional associations, and not to estimate causal effects. The model is generally significant (LR $\chi^2 = 149.54$; $P < 0.001$; pseudo $R^2 = 0.36$). The results indicate that adoption is positively correlated with literacy level, area dedicated to rice, fertiliser use, technical support, and access to banking services. Conversely, rice farming experience and total household area show a negative association. These trends suggest that adoption is driven by a logic of rice specialisation and integration into support networks rather than extensive diversification. In accordance with our methodological framework, these results should be interpreted strictly as correlations: several institutional variables may be subject to selection bias, and their link with adoption cannot be equated with a causal effect.

The positive association between adoption and institutional support variables should be interpreted in light of the Senegalese rice seed distribution system. In rainfed areas in particular, access to improved seed is often mediated by public programmes, seed subsidies and allocation quotas defined by zone and household. This institutional mechanism suggests that technical supervision, subsidized seed access and programme participation are likely to facilitate the use of improved rice varieties. However, because the data are cross-sectional, this study does not formally estimate the causal effect of these services on adoption. Some degree of programme placement or farmer selection may still exist, especially if support is concentrated in better organised

TABLE 6. Probit estimation of factors associated with improved rice variety adoption

Variable	Coef.	Std. Err.	Z	P>|z|
(Intercept)	-3.0448***	0,8487	-3,5875	0,0003
Age	0.0494**	0,0194	2,5537	0,0107
Gender	-0.6941*	0,3933	-1,7645	0,0776
Literacy	1.8064***	0,4225	4,2752	0
Household's area	-0.0463***	0,0178	-2,6006	0,0093
Experience	-0.0598***	0,0167	-3,579	0,0003
Mechanisation	-0.2243	0,3599	-0,6232	0,5331
Area dedicated to rice	0.2185**	0,1102	1,9861	0,047
Training	0.615	0,425	1,4471	0,1479
Organisation	0.5102	0,3701	1,3785	0,168
Fertiliser input on plot	0.9822***	0,3235	3,0359	0,0024
Technical supervision	1.9511***	0,3562	5,4779	0
Bank services access	1.0665***	0,4108	2,5963	0,0094

Statistic	Value
Number of obs.	474
LR chi2	149.54***
Prob > chi2	0
Log likelihood	-130.49629
Pseudo R2	0.3643

zones or among farmers already connected to producer groups. Therefore, the results are best interpreted as strong associations consistent with a public-programme-mediated adoption pathway, rather than as causal estimates.

Level and dynamics of adoption of improved varieties. Analysing the adoption rate of improved varieties provides a better understanding of the extent of technological diffusion across different Senegalese rice-growing systems. The observed regional disparities reflect not only agro-ecological differences but also varying levels of access to irrigation, public policies, improved seeds, and technical support services. Furthermore, not all producers adopt improved varieties simultaneously.

Adoption rates and intensity. The results in Table 7 show a relatively high overall adoption rate of improved varieties, estimated at 57.69%. However, this adoption remains highly differentiated according to production systems and regions.

TABLE 7. Adoption rates by region (plot level)

System	Region	Adoption rate (%)
Irrigated	Saint Louis	96
	Matam	95
Rainfed	Kédougou	85,71
	Kolda	58,48
	Ziguinchor	27,84
	Sedhiou	22,67
	Tambacounda	18,18
Total		57,69

The highest adoption levels are observed in irrigated systems, particularly in Saint-Louis (96%) and Matam (95%). In this area, rice farming is market-oriented. These results confirm the strategic role of the Senegal River Valley in the national modernisation of rice

production. The high adoption rate observed in these areas can be explained by better water management, greater availability of certified seeds, and greater access to extension services and agricultural inputs. Several recent studies conducted in West Africa show that irrigated systems generally offer a more favorable environment for the adoption of improved varieties and the intensification of rice production (Maredia *et al.,* 2022; Johnson *et al.,* 2023).

In rainfed systems, adoption rates are much more varied. In this area, rice cultivation is geared towards subsistence farming. The Kédougou region has a relatively high adoption rate (85.71%), reflecting a local dynamic favorable to the dissemination of varietal innovations, particularly the presence of projects that provide seeds for establishing rice cultivation, which is not a major crop there. Conversely, adoption levels remain lower in Kolda (58.48%), Ziguinchor (27.84%), Sédhiou (22.67%), and Tambacounda (18.18%). These low levels may be linked to the structural constraints that characterise rainfed systems, notably the high dependence on climatic hazards, limited access to improved seeds, and the limited investment capacity of producers. Recent work highlights that climate risks and institutional shortcomings significantly slow the adoption of agricultural technologies in African rainfed systems and that agricultural policies generally benefit areas with hydro-agricultural infrastructure and better-structured supply chains more quickly (Taka*h*ashi *et al.,* 2020; Soullier *et al.,* 2020; Loko *et al.,* 2022; Arouna *et al.,* 2024).

The results presented in Table 6 highlight the importance of analysing adoption not as a binary choice, but through the lens of its spatial allocation intensity. Similar to the work of Ruzzante *et al.* (2021), we observe that the decision to allocate only a fraction of the rice-growing area to improved varieties stems from strategic risk management by households. By maintaining a portion of their traditional sub-varieties, producers create a risk insurance policy, combining the high yield potential of improved seeds with the hardiness of local varieties.

Furthermore, the intensity of adoption at the farm level often faces financial and logistical barriers. As Wossen *et al.* (2017) point out, realising the potential of improved rice varieties requires increased inputs (particularly fertilisers) and labor. Credit constraints and rationing in the certified seed market limit farmers' ability to extend this technology to all their plots. Full adoption thus often appears to be the preserve of farms with either secure and homogeneous land resources or easy access to input and credit markets, while fragmented farms favor a phased adoption, plot by plot.

The results of the adoption typology reveal that the decision to adopt improved rice varieties in Senegal is strongly influenced by land availability and the degree of rice specialisation within the household. In a sample of 474 producers, full and specialised adoption (100% of the rice-growing area) concerns the majority of adopters (53.16% of the overall sample), while partial adoption (<100%) represents only 5.62% of households. The analysis of average farm sizes highlights a rational microeconomic behavior linked to risk management on the one hand, and land constraints on the other.

Partial adopters have the largest rice farms. This relative land abundance allows them to implement a risk diversification strategy by maintaining traditional varieties on a portion of their land, while benefiting from the high yields of improved varieties on the remainder. Conversely, specialised adopters have smaller rice-growing areas. Constrained by space, they cannot afford fragmented adoption and choose to maximise the overall productivity of their farms by converting their entire area to improved varieties. Finally, non-adopters (41.22%) are characterised by the smallest average rice-growing area (1.11 ha), representing less than half of their total farm size (2.41 ha). For these farmers, rice is a secondary crop or strictly for subsistence, making financial investment in certified seeds

and additional inputs less attractive compared to other production opportunities.

Adoption dynamics. Figure 1, showing the distribution of the length of time since the adoption of improved rice varieties, clearly follows Everett Rogers' innovation diffusion curve, reflecting a progressive dynamic of technological appropriation among Senegalese rice farmers. The results show that adoption initially involved a small proportion of Innovators (2.6%) and Early Adopters (7.9%), before spreading massively to the Early Majority (35.2%) and the Late Majority (34.5%). This pattern confirms that the improved varieties have moved beyond the experimental stage and entered a phase of widespread diffusion. Recent studies on the adoption of improved rice in West Africa have reached similar conclusions, showing that the initial phases of adoption remain limited to producers with better access to support systems, before wider diffusion through social imitation and demonstration of performance (Diagne *et al.,* 2021; Loko *et al.,* 2022; Arouna *et al.,* 2024).

The central element of this dynamic lies in identifying the tipping point (the chasm), located at $\mu + 1\sigma$, or 15.11 years of adoption. This threshold marks the transition from marginal adoption by pioneers to mass adoption by the majority of producers. In the Senegalese case, this turning point directly relates to the 2010-2011 period, corresponding to the first operational results of the National Rice Self-Sufficiency Program (PNAR), launched in 2008 and formalised in 2010 (SNDR, 2010). This temporal alignment suggests that public intervention played a decisive role in accelerating the dissemination of improved varieties, particularly through input subsidies, the distribution of certified seeds, and the strengthening of technical support. Several recent studies confirm that public policies and institutional programs are the main catalysts for crossing the technological threshold in African agricultural systems (Soullier *et al.*, 2020; Takahashi *et al.*, 2020; Maredia *et al.,* 2022).

The high concentration of producers in the Early Majority and Late Majority categories also reflects a community-based ripple effect,

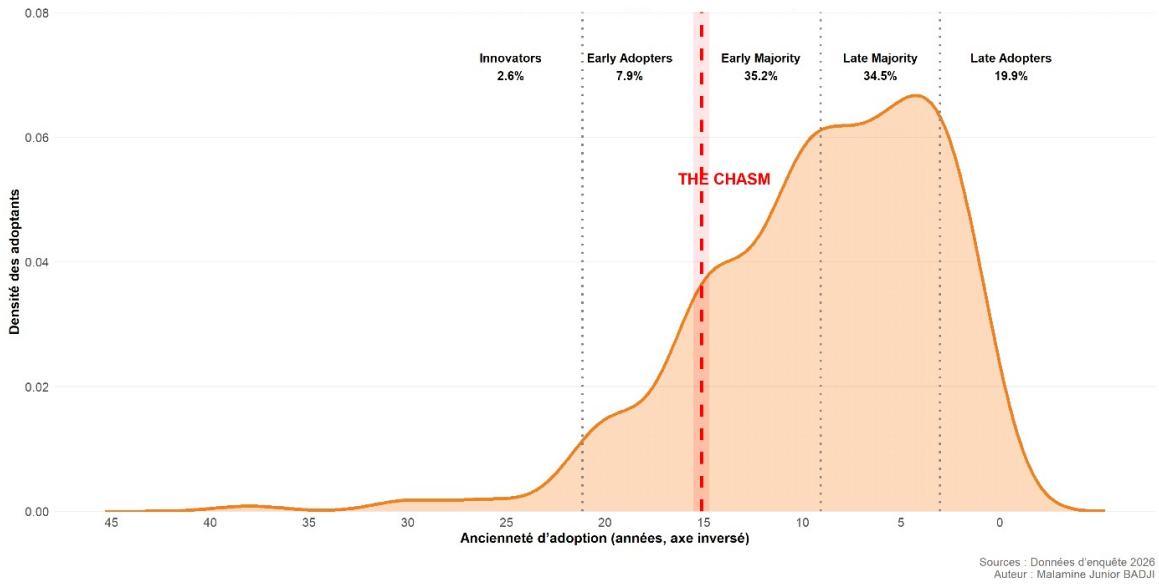

Figure 1. Distribution curve of adopters according to Rogers (1962).

where adoption gradually becomes a productive norm. The work of Johnson *et al.* (2023) shows that in West African rice systems, the diffusion of improved varieties intensifies when yield gains and resilience become visible at the local level. Similarly, the analyses of Manda *et al.* (2020) and Abdulai and Owusu (2021) highlight that agricultural social networks, farmer organisations, and repeated exposure to support policies significantly enhance the rate of diffusion of varietal innovations.

However, the still significant presence of late adopters (19.9%) indicates that certain constraints persist, possibly related to access to certified seeds, input costs, lack of response to varietal preferences, and climate vulnerabilities. This situation aligns with recent observations by Loko *et al.* (2022) and Arouna *e*t *al*. (2024), according to which the diffusion of improved varieties in sub-Saharan Africa remains strongly conditioned by the institutional environment and the economic capacities of farms.

Use of certified seeds. Certified seeds are defined as seeds produced through a controlled process that guarantees genetic purity, a high germination rate, and optimal phytosanitary quality (Soullier *et al.,* 2020). The results (Table 8) reveal a major gap between varietal adoption and qualitative adoption: while the adoption rate of improved varieties is high, the rate of certified seed use is only 35.83% of producers. This disparity is explained by a structural deficit in national production in Senegal, forcing many adopters to use farm-saved seeds from their own previous harvests. A clear territorial divide is observed: the Saint-Louis region dominates with 71.88%, benefiting from the dynamism of private certification systems and a strong market orientation that encourages producers in the Valley to optimise their productivity. Conversely, the rainfed system, like Sédhiou (15.33%) and Tambacounda (18.18%), remains marginalised, suffering from limited access to formal distribution networks and less incentive for seed investment.

Beyond the intrinsic quality of seeds, the performance of a seed system depends on its ability to offer varieties that meet the actual needs of users. A high-performing variety from an agronomic perspective is not necessarily adopted if it does not meet the economic, technical, or environmental preferences of producers.

Survey data show significant heterogeneity in cultivated varieties across regions and production systems. This diversity reflects the existence of specific preferences linked to local agroecological constraints and production strategies. To meet these producer expectations, the formal seed system in Senegal offers a catalog of more than 40 rice varieties (Faye *et al.,* 2021).

Depending on agroecological conditions and producer choices, approximately fifteen improved varieties (13 of which are dominant) are adopted in the various regions of the country.

Table 9 shows that the Sahel 108 variety is the most widespread, followed by NERICA-L 19 cultivated in rainfed areas, and Sédhiou remains the bastion of varietal diversity.

TABLE 8. Typology and intensity of adoption of improved varieties per household

Adopter Profile	Pourcentage	Average rice area	Average household area
Partial adopter (<100% of rice)	5.62	2,07	2,87
Specialised adopter (100% of rice)	53.16	1,52	2
Non-adopter (0%)	41.22	1,11	2,41

TABLE 9. Rate of use of certified seeds by region (plot level)

System	Region	Certified seed rates (%)
Irrigated	Saint Louis	71.88
	Matam	42.9
Rainfed	Kédougou	31.43
	Kolda	53.22
	Ziguinchor	27.84
	Sédhiou	15.33
	Tambacounda	18.18
Total		35.83

Political implications

Alignment between observed diffusion and national objectives. The results of this study reveal a structural gap between the current dynamics of improved variety diffusion and the national ambitions for rice self-sufficiency promoted by the National Rice Self-Sufficiency Program (PNAR) and the guidelines of the new National Rice Development Strategy (SNDR) (2025-2030). Analysis of the diffusion curve (Fig. 1) shows that improved varieties did indeed reach the tipping point (chasm) in 2010–2011, with 35.2% of producers in the Early Majority category and 34.5% in the Late Majority category, confirming widespread diffusion. This dynamic suggests that public intervention through the PNAR has indeed played a catalytic role in accelerating adoption, as demonstrated by Soullier *et al*. (2020) and Maredia *et al.* (2022) in other African contexts.

However, this quantitative diffusion masks a major qualitative weakness: only 35.83% of producers use certified seeds. This overall rate also conceals profound territorial inequalities, with 71.88% use in Saint-Louis compared to 15.33% in Sédhiou and 18.18% in Tambacounda. This divide between irrigated and rainfed systems directly calls into question the effectiveness of public policies in terms of territorial equity and coverage of target populations (Jayne *et al*., 2018). While the national objective of self-sufficiency relies on a generalised increase in productivity, the results suggest that current gains are concentrated on a geographically and structurally restricted segment of better-equipped producers, thus limiting the transformative impact of the policies implemented (Demont and Ndour, 2015).

Furthermore, the yield difference observed between adopters (3,775.86 kg ha^{-1}) and non-adopters (1,488.11 kg/ha) cannot be attributed solely to varietal effects, especially since the majority of adopters do not use certified seeds. Policies must therefore be redesigned around an integrated, high-quality package combining adapted varieties, certified seeds, complementary inputs, agricultural extension services, and market access. This observation aligns with the findings of Loko *et al*. (2022) and Arouna *et al*. (2024), who concluded that the full dissemination of improved varieties in sub-Saharan Africa remains heavily dependent on the institutional environment and the economic capacity of farms.

The study's findings suggest that the effectiveness of public policies depends not only on the availability of subsidies but also on the quality of the dissemination ecosystem. In this regard, the role of the National Agency for Agricultural and Rural Advisory Services (ANCAR), the main national extension and technical support mechanism, appears crucial. The high concentration of adopters in areas with a long history of better support indicates that agricultural advisory services, proximity to research centers (ISRA and AfricaRice in the North), and the intensity of technical support mechanisms largely determine the effective conversion of subsidies into technology adoption.

Gaps identified and levers for action. These four gaps constitute interdependent bottlenecks that limit the structural transformation of the Senegalese rice sector. The institutional gap restricts access to

information and technical advice, the financial gap limits investment capacity, the seed gap compromises quality and agronomic sustainability, while the socio-demographic gap perpetuates structural inequalities.

The recommendations are structured around four complementary strategic axes: (i) institutional and informational strengthening through the expansion and diversification of extension services; (ii) financial inclusion and subsidy reform to broaden access to inputs; (iii) structuring the seed system to guarantee quality and availability; and (iv) social inclusion policies to reduce inequalities in gender and human capital.

The joint implementation of these recommendations should make it possible to move beyond the current stage of fragile quantitative dissemination to achieve qualitative, equitable, and sustainable dissemination, a necessary condition for achieving national rice self-sufficiency objectives.

CONCLUSION

Results of this study have shown that the diffusion of improved rice varieties follows a logistic trajectory, with a major acceleration around 2010-2011, corresponding to the period of stronger institutional support through national rice programmes. This shift marked the transition from limited experimentation to broader diffusion, particularly in irrigated systems. However, the findings also reveal a strong spatial imbalance: adoption is highly concentrated in the irrigated Senegal River Valley, where uptake is close to saturation, while rainfed systems in Casamance and eastern Senegal continue to show lower adoption intensity and weaker access to certified seed.

The empirical results indicate that adoption is not only related to seed availability, but also to farmers' integration into institutional support systems. Access to technical supervision, fertiliser use on plots, literacy, and banking services are positively associated with improved variety adoption. The Probit results confirm these associations, with the model showing good overall fit, but these findings should be interpreted as correlations rather than causal effects. In the Senegalese context, especially in rainfed areas, access to improved seed is often mediated by public programmes, subsidies, and allocation quotas by zone and household. This supports the interpretation that institutional support plays an important role in facilitating adoption, although the cross-sectional nature of the data does not allow a formal estimation of causal impacts.

For Senegal's National Rice Development Strategy, the main policy implication is that varietal diffusion policies should become more geographically targeted. The results suggest that the Senegal River Valley has already reached a high level of improved variety diffusion, whereas the main bottlenecks are now located in the rainfed rice hubs of Casamance and eastern Senegal, particularly in Kolda, Sédhiou, Ziguinchor, Tambacounda and Kédougou. Policy efforts should therefore shift greater resources toward these lagging zones through decentralised seed multiplication systems, stronger extension services, improved access to certified seed, and financial mechanisms adapted to the risk conditions of rainfed rice farming. Closing the gap between varietal adoption and certified seed use will be essential for converting nominal adoption into sustained productivity gains.

This study remains mainly descriptive and exploratory. Although the logistic diffusion model captures the temporal pattern of adoption and the Probit model identifies factors statistically associated with adoption, the analysis does not establish causal relationships. In particular, the observed associations between adoption, technical supervision, subsidies and banking access may partly reflect programme placement or farmer selection. Future research should therefore use panel data, quasi-experimental methods, or instrumental variable approaches to estimate

the causal effects of improved varieties and institutional support on productivity and household welfare. Despite these limitations, the study provides evidence that Senegal's rice policy challenge is no longer only to promote improved varieties nationally, but to correct the spatial imbalance in their diffusion and ensure that rainfed production systems are not left behind.

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REFERENCES

Abate, G.T., Bernard, T. and de Brauw, A. 2018. The impact of agricultural extension on farmers' technology adoption and welfare: Evidence from Ethiopia. *Food Policy* 78:1-16.

Abdulai, A. and Owusu, V. 2021. Adoption of improved agricultural technologies and social networks in Sub-Saharan Africa. *Technology in Society* 67:101741.

AfricaRice. 2022. AfricaRice Annual report 2021: Building resilience through rice research for development. Africa Rice Center (AfricaRice). https://www. africarice.org/_files/ugd/0839e4_55804a2ef7bc47b5944358fef4b85907.pdf

AfricaRice. 2025. Revised National Rice Development Strategy II (NRDS II) 2026-2030. Cotonou, Bénin. https://www.researchgate.net/publication/369901368_NATIONAL_RICE_DEVELOPMENT_STRATEGY_2021_-2030

Arouna, A., Michler, J. D. and Lokossou, J.C. 2017. Contract farming and productivity in rice systems in West Africa. *World Development* 137: 23-30.

Arouna, A., Fatognon, I.A., Saito, K. and Futakuchi, K. 2021. Moving toward rice self-sufficiency in sub-Saharan Africa by 2030: Lessons from 10 years of the Coalition for African Rice Development. *World Development Perspectives* 21: 100291.

Arouna, A., Barry, M. L., Kamano, P. and Yabi, J.A. 2024. Does adoption of improved variety encourage farmers to invest in modern inputs and use good practices? Evidence from rice farmers in Guinea. *Journal of Agricultural and Applied Economics* 56(4):597-620. https://doi.org/10.1017/aae.2024.27

Cochran, W. G. 1977. Sampling Techniques (3rd ed.). New York: John Wiley & Sons.

DAPSA. 2023. Rapport de l'Enquête Agricole Annuelle (EAA) 2022-2023. https://www.dapsa.gouv.sn/sites/default/files/Rapport_EAA%202022_2023_v1.pdf

Demont, M. 2013. Reversing urban bias in African rice markets: A review of 19 national rice development strategies. *Global Food Security* 2(3):172-181.

Demont, M. and Ndour, M. 2015. Upgrading rice value chains in West Africa: *Experimental evidence from Senegal. Global Food Security* 5:70-76.

Diagne, M., Demont, M. and Diaw, A. 2017. Taux et déterminants de l'adoption des variétés améliorées de riz au Sénégal. *Économie Rurale*. pp. 51-68

Diagne, A., Amovin-Assagba, E., Futakuchi, K. and Wopereis, M.C.S. 2021. Estimation of cultivated area, number of farming households and yield for major rice-growing environments in Africa. *Realizing Africa's Rice Promise* CABI. *Chapter* 3(1):33.

Diallo, M. 2022. Effect of seed and fertilizer subsidies on the technical efficiency of rice farmers in Senegal. 50x2030 Initiative Working Paper.

Doss, C. 2018. Women and agricultural productivity: Reframing the issues. *Development Policy Review* 36(1):35-50. https://doi.org/10.1111/dpr.12243

FAO. 2014. The state of food and agriculture 2010-2011: Women in agriculture, closing the gender gap for development. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/i2050e/i2050e00.htm

Faye, O.N., Sock, M., Oh, J.-H., Kim, W.-J., Lee, J.-R., Manneh, B. and Kang, K.-H. 2021. Status of rice cultivation and breeding in Senegal. *Korean Journal of International Agriculture* 32(4):321-334.

Feder, G., Just, R. E. and Zilberman, D. 1985. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change* 33(2): 255-298. https://doi.org/10.1086/451461

Fisher, J., Goldstein, J. and Ramkumar, A. 2025. Rice self-sufficiency initiatives in Indonesia, Bangladesh and Senegal: A comparative analysis. *Development and Change* 56(2):229-253. https://doi.org/10.1111/dech.12878

Foster, A.D. and Rosenzweig, M.R. 2010. Microeconomics of technology adoption. *Annual Review of Economics* 2(1):395-424. https://doi.org/10.1146/annurev.economics.102308.124433

Futakuchi, K. and Saito, K. 2021. History and progress in genetic improvement for enhancing rice yield in sub-Saharan Africa. *Field Crops Research* 267: 108159. https://doi.org/10.1016/j.fcr.2021.108159

Issahaku, G. and Abdulai, A. 2020. Can farm households improve food and nutrition security through adoption of climate-smart practices? Empirical evidence from northern Ghana. *Applied Economic Perspectives and Policy* 42(3):559-579.

Jayne, T.S., Mason, N.M., Burke, W.J. and Ariga, J. 2018. Input subsidy programs and agricultural transformation in Africa. *Food Policy* 75:1-14.

Johnson, J.-M., Becker, M. and Dossou-Yovo, E.R. 2023. Farmers' perception and management of water scarcity in irrigated rice systems in West Africa. *Agronomy for Sustainable Development* 43(32). https://doi.org/10.1007/s13593-023-00878-9

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F. and Mekuria, M. 2015. Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change* 80(3):525-540. https://doi.org/10.1016/j.techfore.2012.08.007

Lecoutere, E., Spielman, D.J. and Van Campenhout, B. 2019. Women's empowerment, agricultural extension, and digitalization: Disentangling information and role model effects in rural Uganda. IFPRI Discussion Paper 01889.

Liverpool-Tasie, L.S.O., Wineman, A. and Young, S. 2020. A scoping review of agricultural technology adoption in Africa: Implications for research and policy. *Food Policy* 92:101-120.

Loko, Y.L.E., Gbemavo, C.D.S.J. and Djedatin, G. 2022. Characterization of rice farming systems, production constraints and determinants of adoption of improved rice varieties in Benin. *Scientific Reports* 12: 4019. https://doi.org/10.1038/s41598-022-07946-2

Malkov, E., Barkowski, S. and Qureshi, Z. 2022. Youth employment in sub-Saharan Africa. *Journal of African Economies* 31(Supplement 1):i37-i62.

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M. and Tembo, G. 2020. Adoption and impacts of sustainable agricultural practices in Africa: Evidence from maize and rice systems. *Food Policy* 99:101965.

Maredia, M.K. and Bambio, Yiriyibin. 2022. Exposure to agricultural technologies and adoption: Evidence from the West Africa Agricultural Productivity Program. *Food Policy* 113:102288.

Moukoumbi, Y.D., Seck, P. A., Futakuchi, K., Manneh, B., Niang, A., Ndour, M. and Ndir, K.N. 2025. Field evaluation of advanced rice lines for adaptability to irrigated and rainfed lowland ecologies in

Senegal. *Plants* 14(3):456. https://doi.org/10.3390/plants14030456

Ogada, M.J., Mwabu, G. and Muchai, D. 2014. Farm technology adoption in Africa. *Agricultural Economics* 51(4):4.

Peterman, A., Quisumbing, A., Behrman, J., and Nkonya, E. 2014. Understanding the complexities surrounding gender differences in agricultural productivity in Nigeria and Uganda. *Journal of Development Studies* 47(10):1482-1509.

Quisumbing, A.R., Meinzen-Dick, R. and Malapit, H. 2021. Gender and agricultural development. *Annual Review of Resource Economics* 13:34-37.

Rodenburg, J., Demont, M., Zwart, S. J. and Bastiaans, L. 2019. Parasitic weed incidence and related economic losses in rice in Africa. *Agriculture, Ecosystems & Environment* 235:306-317.

Rogers, E.M. 2003. Diffusion of innovations (5th ed.). Free Press. https://teddykw2.wordpress.com/wp-content/uploads/2012/07/everett-m-rogers-diffusion-of-innovations.pdf

Ruzzante, S., Labarta, R. and Bilton, A. 2021. Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development* 146:105599. https://doi.org/10.1016/j.worlddev.2021.105599

Seck, P.A., Diagne, A., Mohanty, S. and Wopereis, M.C.S. 2015. Crops that feed the world 7: Rice. *Food Security* 4(1):7-24.

SNDR. 2010. Programme National D'autosuffisance en Riz. Stratégie Nationale de Développement de la Riziculture - JICA, consulté le 5 mai 2026, https://www.jica.go.jp/english/our_work/thematic_issues/agricultural/pdf/senegal_en.pdf

Soullier, G., Demont, M., Arouna, A., Lançon, F. and Del Villar, P.M. 2020. The state of rice value chain upgrading in West Africa. Global Food Security, 25, 100365.

Takahashi, K., Muraoka, R. and Otsuka, K. 2020. Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agricultural Economics* 51(1): 31-45. https://doi.org/10.1111/agec.12539

USDA Foreign Agricultural Service. 2025. Senegal: Grain and Feed Annual 2025. GAIN Report SG2025-0008.

Wainaina, P., Tongruksawattana, S. and Qaim, M. 2016. Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. Agricultural Economics 47(3):351-362. https://doi.org/10.1111/agec.12235

Wooldridge, J.M. 2010. Econometric analysis of cross section and panel data (2nd ed.). MIT Press. 1096pp

Wossen, T., Abdoulaye, T., Alene, A., Haile, M. G., Feleke, S., Olanrewaju, A. and Manyong, V. 2017. Impacts of extension access and cooperative membership on technology adoption and household welfare. *Journal of Rural Studies* 54:223-233. https://doi.org/10.1016/j.jrurstud.2017.06.022