Economic Impact of Hybrid Maize Seed on Agricultural Production and Income in Burundi

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Abstract: Agricultural innovation helps to improve productivity, increase income and ensure food security. Burundi, like other countries, invests in agricultural research and development. However, the adoption of new agricultural technologies remains low, resulting in average yields below the potential of improved varieties and in particular hybrid maize seeds. This study aimed to assess the impact of hybrid maize seed adoption on production, farm income and food security of Burundian farm households.

A field survey was conducted on a sample of 87 individuals comprising adopters (treatment group) and non-adopters (control or comparison group) of hybrid maize seed. This was done with a view to comparing the agricultural performance of the two groups and drawing conclusions based on the similarity of observable characteristics. For this purpose, the propensity score matching method was used in the econometric analysis of the data. The impact of adoption was then estimated on maize production and household farm income.

The econometric results show that the adoption of maize hybrids has a positive and significant impact on the agricultural production and income of Burundian farmers. Indeed, the impact on production or ATT (Average Treatment for the Treated) is 1233 Kg with a T-test of 5.076 while the impact on agricultural income (ATT) is 2,271,261 BIF with a T-test of 4.901. In terms of technical efficiency, it should be noted that the average technical efficiency of hybrid producers is 0.90, while it is 0.45 for producers of 'all maize'. The major constraints mentioned are the unavailability of seed and the high cost of hybrid maize seed.

***Keywords**: Seed, Hybrid Maize, Common Maize, Impact, Production, Income.*

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I. INTRODUCTION

In Burundi, agriculture alone contributes 39.6% to GDP, provides 84% of jobs, supplies 95% of the food supply and is the main provider of raw materials to the agro-industry (PND, 2018).

The agricultural sector is therefore the main source of economic growth and the foundation on which the process of transforming the Burundian economy must be built. With this in mind, the rural sector's contribution to wealth creation and the fight against poverty will be based on increasing production of food crops, export crops, livestock, fish farming, safeguarding natural resources and sustainable environmental management (PNSA, 2009).

Among Burundi's main food crops, cereals occupy a very important place. Over 70% of food production comes from cereals. Maize is the most widely grown cereal throughout the country, followed by sorghum, rice, wheat and eleusine(Kameya, 2014).

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➢ *Box: Summary Map of Burundi's Agricultural Economy as a Framework for Strategic Action*

Burundi's agricultural economy is based on three main pillars (Food, Cash and Livestock) in a multifaceted paradigm of agricultural speculations, practices and, in our opinion, based on a multitude of actors (farmer-producers, OASC, Research Centers, Universities, etc.) and producer-consumer partnerships that policies should consider to promote short circuits and ensure fair incomes for producers.

These 3 pillars form a compass base grouped into the following five main groups:

A.ANNUAL FOOD CROPS:

Cereals: Corn, Rice, Wheat, Sorghum and Millet

Legumes: Beans, Peas, Peanuts and Soybeans

Roots and tubers: Cassava, Sweet potato, Potato, Colocase

Fruits and vegetables: Bananas, pineapples, citrus fruits, papayas, Japanese plums, squash, carrots, tomatoes, amaranths, spinach, leeks and peppers.

Hors sols: Edible mushrooms (Pleurotes, Shiitakes, etc.).

B. PERRENIAL/CASH CROPS

Industrial crops: coffee, oil palm, tea, sugar cane, cotton.

C.BREEDING (LIVESTOCK)

Cattle, Chicken, Pork, Goat, Rabbit, etc.

Agro-ecological practices seem to be positioning themselves as leaders and catalysts for all the pillars of the community agricultural economy, in terms of organic manure production and management, plant protection and protection around income-generating agricultural activities, best agricultural practices, association farming systems and techniques to promote collective or individual post-harvest management.

Maize research in Burundi dates back to the days of INEAC around 1929, at the Gisozi station. At that time, several varieties of diverse origins were introduced and evaluated. Trials and introductions continued after INEAC was taken over by ISABU. It is the leading cereal in Burundi in terms of both total annual production and area sown. It is grown practically everywhere, but especially in the high-altitude zone where it is the staple food for the population (KAMEYA, 2014). However, grain yields are very low among Burundian farmers (less than 1 t/ha) compared with those obtained at the various ISABU Research Stations (3 t/ha). Farmers are not aware of the use of selected seeds, especially for maize, which is a cross-pollinated plant (Nkurunziza et al.,2012).

In general, farm households in Burundi use mainly local seeds and seedlings. The proportion of farm households using improved seeds and seedlings was low in all three agricultural seasons. The proportion was estimated at 19.5% in 2017 A season, 2.6% in B season and 1.6% in 2017 C season. The situation of improved maize seed use is very low with a national average proportion of 4.3% (ENAB, 2018).

A study carried out in 2008 revealed that inadequate application of inputs, as well as poor selection of appropriate varieties for given ecologies, contributed to lower yields (M.Tahir et al., 2008). The introduction of maize hybrids can double yields on the same area.

In the past, a number of studies have shown that hybrid maize adoption has a positive impact on household welfare (O. T. Westengen et al., 2014; F. Kutka, 2011; R. Lunduka et al., 2012). Using propensity score matching and endogenous change regression (Khonje et al. (2015) found that hybrid adopters achieved better yield, consumption and food security. Hybrid adoption is viable and profitable in Nigeria (A. B. Olaniyan and E. O. Lucas, 2004). Becerril and Abdulai (2010) examined the adoption of improved maize germplasm in Oaxaca and Chiapas, Mexico, and found that hybrid maize adoption had a positive impact on household welfare. In Malawi, a study showed that hybrids were adopted by farmers interested in higher yields and drought-tolerant attributes, while OPVs were mainly adopted by farmers interested in early maturity (R. Lunduka et al., 2012). Drought-tolerant hybrid maize (DTM) is more profitable than open-pollinated varieties and also offers resistance to changing climatic conditions (P. S. Setimela et al., 2017). DTM has the potential to generate huge cumulative benefits for producers and consumers in developing countries, contributing to the achievement of the Sustainable Development Goals (SDGs). Although maize hybrids offer higher yields than OPVs, there are several barriers to the adoption of maize hybrids, such as high prices and unavailability of seeds (M. R. Karim et al., 2010).

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With the price of hybrid maize seed high in Burundi, smallholders cannot afford to buy it, forcing them to grow open-pollinated varieties. Around 84% of Burundian farmers are smallholders (PND, 2018), and their limited ability to purchase hybrid maize seed is one of the reasons for its low adoption. Providing subsidies for hybrid maize seed, as well as improving distribution channels and extension services, could help smallholders adopt hybrid maize.

However, none of these studies has examined the impact of hybrid maize seed in Burundi. This study is therefore the first to examine the factors influencing hybrid maize adoption and its impact on maize yields and household income levels in Burundi. The rest of the paper is organized as follows: section 1 is an introduction, section 2 presents the conceptual framework, section 3 presents the methodology, section 4 presents the description of the variables, section 5 outlines the empirical results and section 6 is dedicated to the discussion of the results. The paper concludes with some recommendations in section 7.

II. CONCEPTUAL FRAMEWORK OF THE STUDY

We consider that maize growers have two options: to grow either maize hybrids, or all-corn or open-pollinated varieties. However, this choice is a complex one, as several factors influence this decision. The conceptual framework presented in Figure 1 shows that exploiting the economic potential of hybrid maize seed is the fruit of a well-developed and implemented national seed plan, and the involvement of maize industry players. The high price of hybrid seed and the lack of scientific knowledge and information on hybrid maize varieties are the main constraints to the adoption of hybrid maize seed. However, adopters have higher maize yields, higher income levels and higher overall well-being.

According to SAN (2018), current food crop yields are well below potential as a result of insufficient use of high-performance inputs, poor exploitation of agricultural potential and low capacity of production support services. Among the constraints mentioned is the lack of seeds and low use of other high-performance inputs. Limited access to seeds is a consequence of this situation, and favors seed imports from foreign companies, creating dependence on the outside world. In terms of the National Agricultural Strategy (2018), the country's projection is to ensure sustainable food and nutritional security for all via sustainable growth in agricultural production. Our research is therefore in line with this vision, with the aim of documenting the factors driving the adoption of hybrid maize seeds, in order to enhance their economic potential and thus contribute to the promotion of commercial agriculture as a source of income and well-being.

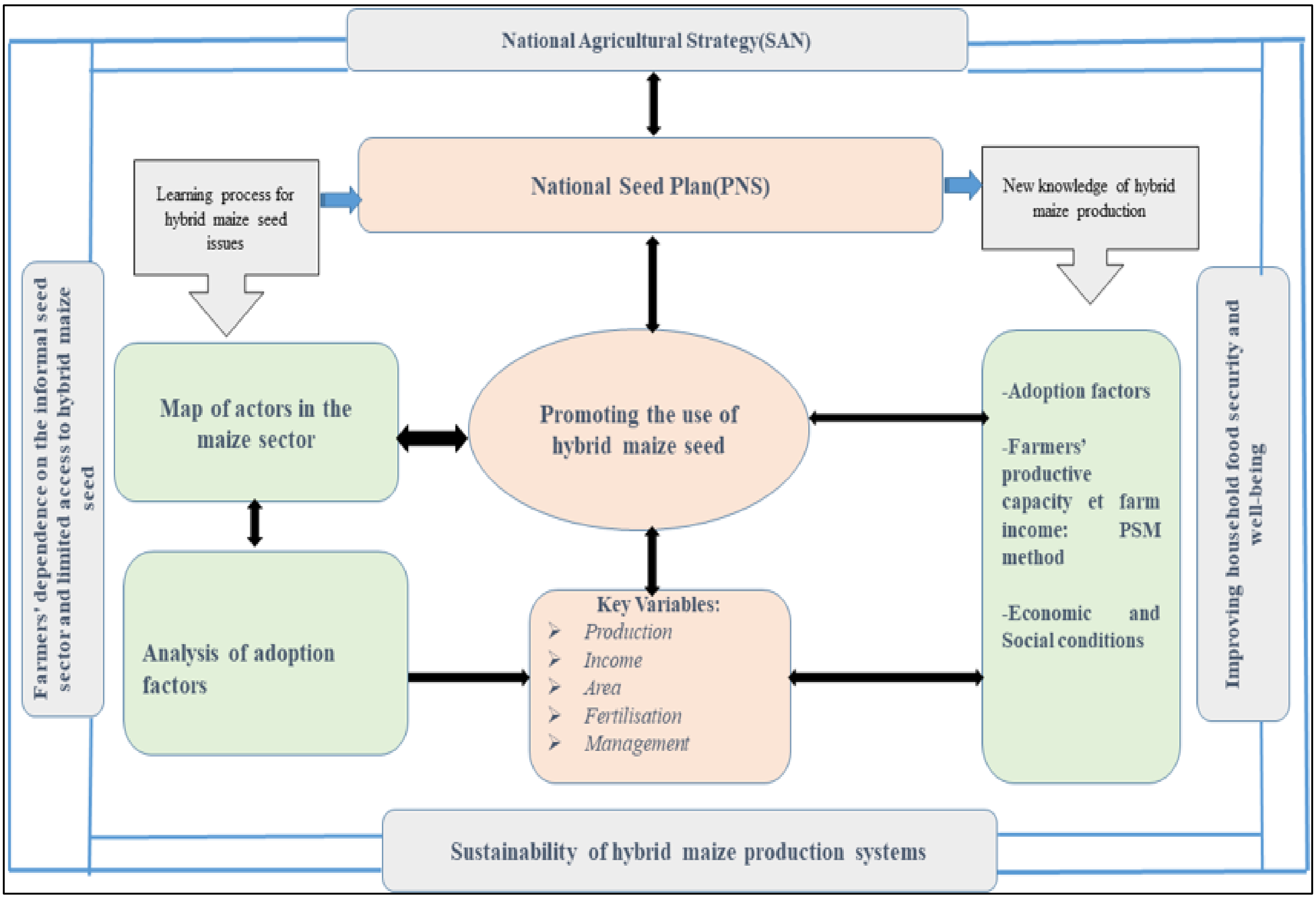

Fig 1: Conceptual Framework of the Study (Adapted from Ngendakumana et al. 2014)

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III. MATERIALS AND METHODS

A. Characteristics of the Study Area

The study was carried out in the Imbo plain, in two provinces, namely BUBANZA and CIBITOKE, in the communes of Gihanga and Mpanda for BUBANZA province, and Buganda and Rugombo for CIBITOKE province. These provinces have benefited from various seed granting projects, in particular the Projet Régional de Développement Agricole Intégré dans les Grands Lacs (PRDAIGL). First-time beneficiaries receive 100% of the hybrid maize seed and inputs they need. Those receiving support for the second year receive half the seed and inputs they need, while those receiving support for the third time are entitled to 20% of the seed and inputs for the A 2021-2022 cropping season.

The Imbo plain is one of Burundi's 5 ecological zones. It lies in western Burundi between Lake Tanganyika and the foothills of the Mumirwa region. It is the westernmost and lowest-altitude region of Burundi. The Imbo plain is made up of vast areas drained by the Rusizi river to the north and the thin coastal plain along Lake Tanganyika to the south. The limits of the Imbo plain lie between the altitude of 774 m (the mean lake level) and the isohypse of 1000 m (INECN, 2013).

Climatically, the ecological region of the Imbo plain is characterized by rainfall of 800 to 1,100 mm spread over 7 to 8 months, but some parts, especially in the north, are chronically arid. The average annual temperature is over 25°C, with highs of over 30°C and lows of under 15°C. Relative humidity is estimated at 70%. With an area 10% the size of Burundi, and a population density of 300 inhabitants per km², the Imbo plain is one of the most densely populated regions in the country. Its economy is largely dependent on agriculture. It lends itself to a wide range of crops. Agriculture, practiced on alluvial soils, consists of food crops and industrial crops. The former include, in order of importance, rice, grown mainly in the northern part of the region, and oil palms, which predominate in the southern part of the Imbo plain. Cattle are raised mainly in the central and northern parts of the region (INECN, 2013).

B. Sampling and Data Collection

This study aims to document the factors influencing households' decision to adopt hybrid maize and its impact on household welfare using primary data collected from farm households in two provinces of Burundi, namely Bubanza and Cibitoke.

A multi-stage sampling procedure was adopted to investigate the target farm households. In the first stage, we selected two of the country's provinces, BUBANZA and CIBITOKE. In the second stage, we selected two communes from each province, and in the third stage, we collected information from 87 farmers, including both adopters and non-adopters. The sample size was calculated according to

Pascal Ardilly's (2006) budget constraint formula:

$$n = \frac{C}{c}$$

Where n is the sample size, C is the total budget allocated to the survey and c is the budget required for a single respondent.

So this formula sometimes has constraints, since we can find a sample size that doesn't represent the population. But according to the normal law, the sample size must be greater than or equal to 30. Under the conditions of the study, the size is given by the ratio between the total budget allocated to the survey and the cost necessary for a single respondent, as follows:

$$n = \frac{C}{c} = \frac{609\,000 Fbu}{7000\, Fbu} = 87 \text{ respondents}$$

Analytical data were collected using a questionnaire recorded in Kobocollect software. To facilitate data collection, a pen, a notebook and a Smartphone were used. These data were supplemented by a synthesis of the literature obtained by documentary research using open-access academic search engines such as Microsoft Academic Search, FreeFullPDF and Google Scholar, as well as Google for books and a few documents relating to this work. After data cleaning and variable coding, suitable software such as Excel and STATA were used for analysis.

The table below shows the study variables.

Table 1: Description of Variables Studied

Variables	Description
Age	Producer's age (in years)
Hybr	1 if the producer has benefited from hybrid corn seed and 0 otherwise
Experience_M	Experience in corn production (number of years)
Framing	1 if the producer has received training and 0 otherwise
Propr_exploit	1 if the producer owns the farm and 0 otherwise
Area	Field area in ares
Fertilization	Average use of organo-mineral fertilizers in Kg (here, Urea and KCl)
Production	Average maize production in Kg
Prod_Mais_Hybr.	Average production of hybrid maize in Kg
Prod_Mais_tout_venant	Average maize production in Kg
Rev_moy	Average annual income of a corn producer

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C. Econometric Methods

For the analysis of factors influencing the adoption of hybrid maize varieties, the bivariate probit model was chosen as it is a binary choice econometric model, **i**.e. a choice between two options. It is characterized by the fact that it is based on a standard normal cumulative distribution**.** This is a function that reports the possibility of the said variable having a value less than or equal to a certain number, which functions as a threshold[1] . For this investigation, the model uses the primary dependent variable, i.e. 1 if the farmer has adopted the hybrid maize variety and zero otherwise. Let's consider an equation that explains the dependent variable Y, as a function of one or more independent variables (X): $\mathbf{Y = a + bX_i}$. Thus, when Y is above a certain threshold, a decision is made or not, or a certain event occurs or not.

Next, the propensity score matching (PSM) approach was used to analyze the impact of hybrid maize adoption on yield, income and poverty level. PSM is defined as the conditional probability that a farmer will adopt the new technology, given pre-adoption characteristics (Rosenbaum and Rubin, 1983). SHP creates the conditions for a randomized controlled experiment and then matches similar adopters with similar non-adopters. Here, the propensity score matching (PSM) approach was implemented by employing 4 matching algorithms, namely (i)nearest neighbor matching (NNM), (ii)kernel-based matching (KBM), (iii)radius matching (RM) and (iv)stratification matching(SM). Using SHP, the impact of hybrid maize seed adoption (average treatment effect on treated (ATT) indicates the difference in outcome between households that adopted hybrid maize seed versus similar households that did not) was estimated on maize production and household income. This corrected for sample selection bias.

IV. EMPIRICAL RESULTS

A. Descriptive Statistics Variables Studied

Variable descriptions and descriptive statistics are presented in Table 2. The average age of the farmers is 44 years, with a standard deviation of 13 years, which shows a great variability in the age of the respondents. Maize-growing experience is 20 years.

Table 2: Descriptive Statistics for Quantitative Variables

Variables	**Average**	**Std. Dev.**
Age	43.74713	12.95091
Hybr	.3103448	.4653167
Experience_M	19.68966	12.75467
Framing	.1264368	.3342676
Propr_exploit	.8390805	.3695869
Area	40.70115	52.59916
Fertilization	49.79885	55.9873
Production	807.8161	1107.285
Prod_Mais_Hybr.	1684.815	1406.398
Prod_Mais_tout_venant	413.1667	636.5252
Rev_moy	1557759	2043855

Around 84% of farmers own land, and the average area is 41 ares. Average maize production is 808 kg for all farmers. Hybrid maize growers produced 1685 kg, while other maize growers produced 413 kg.

The average annual income of a maize grower is around 1,557,759 Fbu. However, it varies widely between producers, with a standard deviation of 2,043,855 Fbu. The minimum is 40,000 Fbu and the maximum 8,400,000 Fbu.

Table 3: Descriptive Statistics of Quantitative Variables for the Two Groups, Beneficiaries and Non-Beneficiaries

Hybr = 0

Variable	Obs	Mean	Std. Dev.	Min	Max
Production	60	413.1667	636.5252	20	3500
Income	60	826333.3	1273050	40000	7000000
Age	60	43.11667	12.44117	18	68
Propr_expl	60	.7666667	.4265219	0	1
Area	60	35.36667	47.84463	4	250
Fertilisat~n	60	45.24167	57.9115	0	260
Member_Assoc	60	.3166667	.4691018	0	1
Experience_M	60	19.48333	12.97127	1	50
Framing	60	.1333333	.3428033	0	1

[1] https://economy-pedia.com/11040705-probit-model

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Table 4: Descriptive Statistics of Quantitative Variables for the Two Groups, Beneficiaries and Non-Beneficiaries

Hybr = 1

Variable	Obs	Mean	Std. Dev.	Min	Max
Production	27	1684.815	1406.398	40	5000
Income	27	3183148	2482265	60000	8400000
Age	27	45.14815	14.16307	25	80
Propr_expl	27	1	0	1	1
Area	27	52.55556	61.19787	2	300
Fertilisat~n	27	59.92593	51.02332	10	200
Member_Assoc	27	.3333333	.4803845	0	1
Experience_M	27	20.14815	12.48908	3	50
Framing	27	.1111111	.3202563	0	1

The variable "Hybr =0" indicates the group of 60 non-beneficiaries of hybrid maize seed, while the variable "Hybr =1" indicates the group of 27 beneficiaries.

We note that those who benefited from hybrid maize seed produced 4 times more (1684.815 Kg) than those who did not (413.1667 Kg). Income was also almost 4 times higher, i.e. 3,183,148 Fbu versus 826,333.3 Fbu. This can be explained, among other factors, by the high average area of 52.5 ares for beneficiaries versus 35.3 ares for non-beneficiaries. The average age of beneficiaries is 45, while that of non-beneficiaries is 43.

B. Factors Influencing the Production

The other variables, such as age, membership of an association, experience in production and supervision, were not significant and therefore did not explain household production or farm income.

The Hybrid variable is positive and highly significant at the 1% threshold, meaning that being a beneficiary has a strong influence on production and hence farm income. Its influence on production is around 1077.29. The size of the land owned by the farm household is positive and highly significant at the 1% threshold, meaning that increasing the area strongly increases farm production. In fact, a 1% increase in land area increases agricultural production by 11%. Farmers with large landholdings are most likely to adopt hybrid maize, mainly for two reasons: (1) farmers with large landholdings are able to invest in expensive hybrid maize seed, and (2) farmers with large landholdings are able to maximize production and income by investing in the new technology.

Fertilizer use is positive and significant at the 2.4% threshold, meaning that fertilizer have a strong influence on production. In fact, this influence (1%) is measured by a 3.79% increase in production. The price per kg variable is negative and significant at the 1% threshold, meaning that hybrid maize seed is expensive and inaccessible to small producers, which has a negative influence on production. In fact, a 1% increase in price leads to a 21% reduction in production, which could have been achieved by using hybrid seed. Other variables such as age, land ownership, association membership, production experience and management are not significant and therefore do not explain household production and hence farm income. However, as the age coefficient is negative, this implies that younger farmers are more likely to adopt hybrid maize than older farmers. This could be explained by the fact that younger farmers are more aware and more willing to try out new technologies than older farmers.

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Table 5: Factors Explaining Production

Source	SS	df	MS			
Model	80262867.1	8	10032858.4	Number of obs	=	87
Residual	25180018	78	322820.743	F(8, 78)	=	31.08
Total	105442885	86	1226080.06	Prob > F	=	0.0000
				R-squared	=	0.7612
				Adj R-squared	=	0.7367
				Root MSE	=	568.17

Production	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Hybr	1077.299	134.924	7.98	0.000	808.6859	1345.912
Age	-4.174797	5.771906	-0.72	0.472	-15.66578	7.316186
Superficie	10.91315	1.790107	6.10	0.000	7.349316	14.47697
Fertilisation	3.792979	1.641605	2.31	0.024	.524794	7.061165
Prix_Kg	-.2127969	.0764757	-2.78	0.007	-.3650483	-.0605456
Membre_Assoc	-130.5055	141.8818	-0.92	0.361	-412.9705	151.9594
Experience_M	2.339081	5.963017	0.39	0.696	-9.532374	14.21054
Encadrement	-300.0802	194.0486	-1.55	0.126	-686.4013	86.24091
_cons	496.9659	262.1816	1.90	0.062	-24.99763	1018.929

Table 6: Marginal Effects of the Model Variables
Average marginal effects
Number of obs = 87
Model VCE : OLS
Expression : Linear prediction, predict()
dy/dx w.r.t. : Hybr Age Superficie Fertilisation Prix_Kg Membre_Assoc Experience_M Encadrement

	dy/dx	Delta-method Std. Err.	t	P>|t|	[95% Conf.	Interval]
Hybr	1077.299	134.924	7.98	0.000	808.6859	1345.912
Age	-4.174797	5.771906	-0.72	0.472	-15.66578	7.316186
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Experience_M	2.339081	5.963017	0.39	0.696	-9.532374	14.21054
Encadrement	-300.0802	194.0486	-1.55	0.126	-686.4013	86.24091

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C. Production Costs and Profitability

Table 7 shows the costs of production for all-corn and hybrid corn. The average cost of production for all-corn is 341,786 Fbu, while the cost of production for hybrid is 398,742 Fbu. Production costs for hybrid maize are high, mainly due to the higher cost of seed, while other operating costs are almost the same for maize and hybrids.

The net profit per acre from growing maize is 23,409 Fbu, compared with 60,863 Fbu for hybrids.

Table 7: Comparison of Production Costs (all-corn vs. hybrid corn)

Operation	**Corn, all types**	**Hybrid corn**
Production costs (in Fbu)	341 786	398 742
Production (Kg)	413,1	1684,8
Income (in Fbu)	826 333	3 183 148
Average area (in ares)	35,3	52,5
Net profit per are (in Fbu)	23 409	60 863

D. Propensity Score Matching with Common Support

➢ *Treatment Status*

The hybrid maize treatment variable shows that 60 individuals did not benefit from hybrid maize seed, whereas 27 individuals did. There are many more observations in the comparison group than in the treatment group. This is typical of matching models. We need a large comparison sample to find a good match in the treatment (beneficiary) group. The sample of potential counterfactuals for treated or beneficiary units represents 58.72% of the total.

Table 8: Treatment Status

Variables	Freq.	Percent	Cum.
No beneficiaries	60	68.97	68.97
Beneficiaries	27	31.03	100.00
Total	87	100.00	

➢ *Propensity Score Estimation*

The table below shows the propensity scores or predicted probabilities of the respondents, and then compares them.

Table 9: Propensity Score Estimation

Estimated propensity score				
	Percentiles	Smallest		
1%	.2967566	.2967566		
5%	.3053023	.2973037		
10%	.309566	.3011055	Obs	65
25%	.3273804	.3053023	Sum of Wgt.	65
50%	.3592632		Mean	.3810918
		Largest	Std. Dev.	.0743777
75%	.4027027	.5305366		
90%	.4562466	.5629345	Variance	.005532
95%	.5305366	.5721584	Skewness	1.856592
99%	.7044761	.7044761	Kurtosis	7.618883

Source: Authors' Calculations

Before moving on to impact analysis, it is necessary to calculate the propensity scores or predicted probabilities and carry out matching; in other words, to compare comparable observations between the group of beneficiaries and non-beneficiaries on the basis of similar scores.

The above table shows that the average propensity score or average predicted probability of all individuals is 0.38. The standard deviation is 0.07. The standard deviation is 0.07. Note that 25%, 50% and 75% of individuals have scores of 0.32, 0.35 and 0.40 respectively.

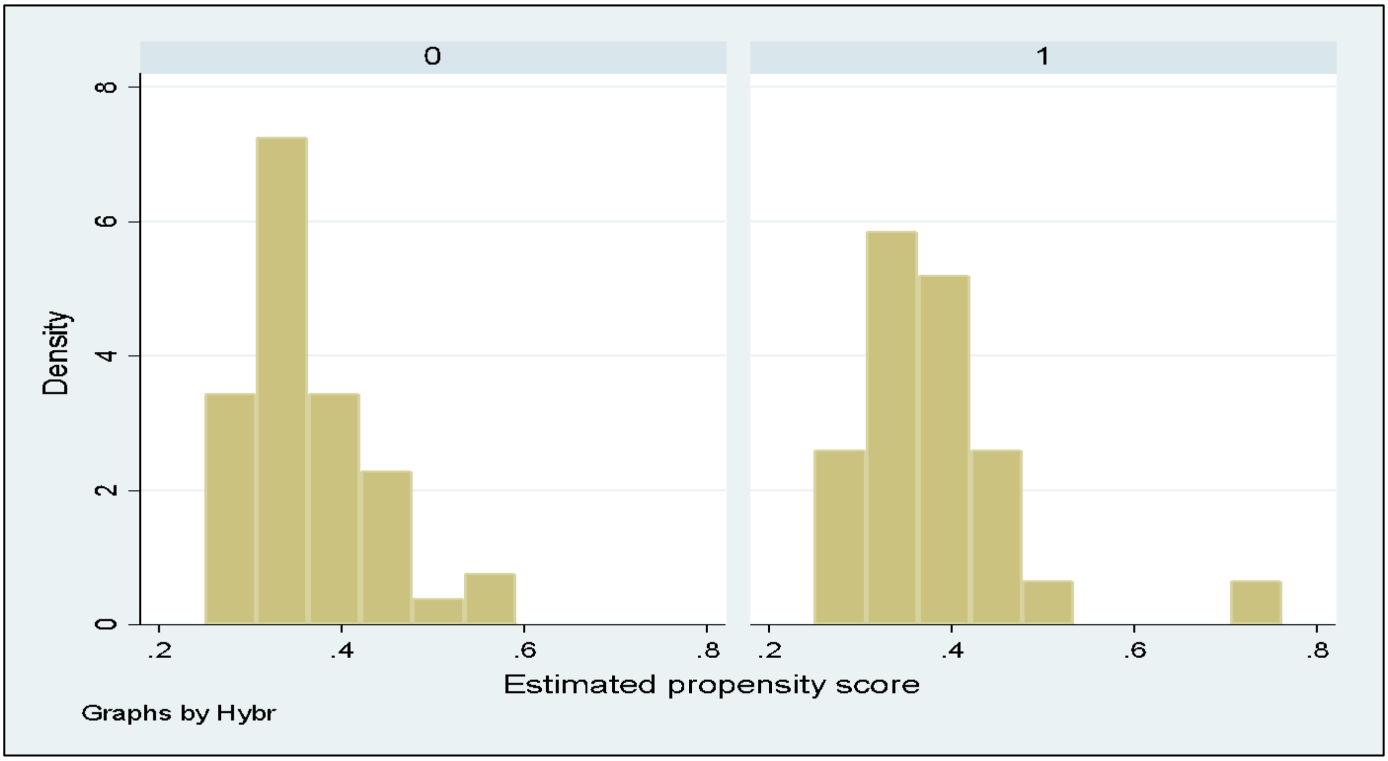

Fig 2: Distribution of Propensity Scores in the Two Groups, Beneficiaries and Non-Beneficiaries

We note a similar distribution of propensity scores, which will enable us to carry out a good matching of the two groups and thus measure the impact satisfactorily.

- *Impact of Hybrid Maize Seed on Production and Farm Income*

The impact of hybrid maize adoption on farm production and income was estimated using the propensity score matching (PSM) approach, and the results are presented in Tables 10 and 11. The PSM analysis was carried out using four different matching algorithms, namely nearest neighbor matching (NNM), kernel-based matching (KBM), radius matching (RM) and stratification matching(SM).

Using SHP, the impact of hybrid maize seed adoption (Average Treatment effect of the Treated-ATT) (ATT indicates the difference in outcome between similar households that adopted hybrid maize and similar households that did not adopt hybrid maize) was estimated on maize production and household income. The impact on maize production is positive and highly significant, demonstrating that adopters have higher yields than non-adopters. Similarly, the impact on household income is also positive and highly significant, meaning that adopters have higher income levels.

Table 10: Impact of Hybrid Maize Seed on Production

Matching algorithms	n.treat.	n.contr.	ATT	Std. Err.	t
NNM	27	16	1116.667	242.160	4.611
RM	26	38	1233.196	242.924	5.076
KBM	27	38	1228.871	267.778	4.589
SM	26	39	1081,320	405,519	2,667

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Table 11: Impact of Hybrid Maize on Farm Income

Matching algorithms	n.treat.	n.contr.	ATT	Std. Err.	t
NNM	27	16	2046852	260530.6	7.856
RM	26	38	104815	289142.8	8.392
KBM	27	38	2271261	463410.8	4.901
SM	26	39	2122832	496265	4.278

Source: Authors' Calculations

➢ *Technical Efficiency of Maize Growers*

Despite estimating the impact of hybrid maize on production and income, it is also crucial to estimate and compare the technical efficiency levels of hybrid maize and "all-corn" producers. We used STATA software to estimate the technical efficiency of maize growers, and present the results in Table 12.

The average technical efficiency of hybrid corn growers is 0.90, while the average technical efficiency of "all-corn" growers is 0.45. The difference in the level of technical efficiency between hybrid and "all-corn" growers indicates that there is a significant difference (double) in the level of efficiency.. The value of γ tells us that the deviation from the frontier is explained by technical inefficiency at 3% and 97% of this variability is then attributed to random factors for hybrid maize seed adopters and 99% of the deviations from the frontier are explained by technical inefficiency for non-adopters and only 1% is attributed to random factors.

Table12: Technical Efficiency of Maize Growers

Producer category	Average E.T(Technical efficiency)	Standard deviation	Minimum	Maximum	γ
Hybrid corn	**0,9079839**	0,1191349	0,6666216	0,9993322	0,03
Corn, all types	**0,4502353**	0,2989919	0,0620254	0,9999997	0,99

Source: Authors' Calculations

We estimated technical efficiency levels from a stochastic production frontier using the Cobb-Douglas specification. The variables taken into account are production (in Kg), fertilization, farm size and experience in maize cultivation.

➢ *Constraints on hybrid maize production*

Among the constraints mentioned, the unavailability of seeds was singled out by most farmers (55.5%). Other constraints include the high cost of seeds, the need for phytosanitary products for hybrids, lack of resistance to pests and diseases, insufficient water, lack of phytosanitary products, etc.

To overcome these constraints, farmers recommend that seeds be made available on time and at an affordable price (2000 to 3000Fbu per Kg instead of 8850Fbu), and that sufficient water and phytosanitary products be made available.

The empirical results lead to the conclusion that hybrid maize adoption has a positive and significant impact on maize yield, household income and general household welfare. The level of technical efficiency of farmers who adopt hybrid maize seed is also higher than that of farmers who do not. Care must be taken to ensure that small-scale farmers have access to affordable maize hybrids. Hybrid maize seed prices need to be reduced through local production, as seed is currently mainly imported.

V. DISCUSSION OF RESULTS

A. Effect of Hybrid Seed use on Production and Income

The results show that the beneficiaries of hybrid maize seed produced 4 times more (1684.815 Kg) than those who did not (413.1667 Kg). This is due to the fact that hybrid seeds generally germinate faster and plants develop more vigorously. As a result of the heterosis effect, these plants develop better and are ahead of non-hybrid plants.

These results have been demonstrated by a number of authors who have underlined the superiority of maize hybrids in terms of yield and income. M. Tahir et al. (2008) explain that the introduction of maize hybrids can double yields on the same area. A. Huang et al. (2010) concur, asserting that the adoption of these hybrids considerably increases maize yields. In Malawi, a study showed that hybrids were adopted by farmers interested in higher yields and drought-resistant attributes, while all-comers were mainly adopted by farmers interested in early maturity (R. Lunduka et al., 2012).

Income is about 4 times higher, i.e. 3,183,148 Fbu versus 826,333.3 Fbu. With regard to the impact of hybrid maize on income, the results obtained are corroborated by the conclusions of certain authors. Mendola (2007) and Wu et al. (2010) found a positive impact of the adoption of agricultural innovations on income and poverty reduction.

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Mendola (2007) found that the income of technology adopters was 30% higher than that of other producers. Kassie et al (2011) also highlighted the positive impact of adopting improved groundnut varieties on net incomes and poverty reduction in Uganda. Becerril and Abdulai (2010) examined the adoption of improved maize germplasm in Oaxaca and Chiapas, Mexico, and found that hybrid maize adoption had a positive impact on household welfare.

In the past, a number of studies have shown that the adoption of hybrid maize has a positive impact on household welfare (O.T. Westengen et al., 2014; F. Kutka et al., 2011; R. Lunduka et al., 2012). Using propensity score matching and endogenous switching regression, Khonje et al. (2015) found that hybrid adopters achieved higher yield, consumption and food security. Hybrid adoption is viable and profitable in Nigeria (A.B Olaniyan and E.O Lucas, 2004).

B. Fertilizer Application and Agroecological Practices

The results show that the use of fertilizers is positive and significant at the 10% threshold, meaning that fertilizers, among other factors, significantly increase production. However, a study carried out in 2008 showed that inadequate application of inputs, as well as poor selection of varieties adapted to given ecologies, contributed to lower yields (M. Tahir et al., 2008).

The rate of fertilizer use is very low despite the intention of the National Fertilizer Subsidy Program in Burundi (PNSEB) to give farmers access to low-cost fertilizers. On average, only 19.1 kg of fertilizer is applied per hectare of arable land (World Bank, 2021). The main obstacles to increased fertilizer adoption are the low purchasing power of the farming population and limited awareness among farmers. To ensure the best yields and respect for the environment, fertilizer application and organic waste composting must be combined with the many other agroecological practices such as natural biofertilizers, crop association systems and innovative tillage systems in soil fertility improvement and family farm management. It's worth noting that over the last few decades, agroecological practices have positioned themselves as leaders and catalysts for the whole community in questions of organic manure production and management, plant protection and defense around income-generating agricultural activities; best agricultural practices, association farming systems and techniques to promote collective or individual post-harvest management.

C. Price-Related Adoption Constraints

Although maize hybrids offer higher yields than conventional varieties, there are several obstacles to the adoption of maize hybrids, such as high prices and unavailability of seed (M. R. Karim et al., 2010). In fact, the results of the study show that 55.5% of farmers were indignant about the unavailability of seed, compared with 48.15% who felt that hybrid seed prices were high.

With the price of hybrid maize seed high in Burundi, smallholders cannot afford to buy it, forcing them to grow off-the-shelf maize varieties. Around 84% of Burundian farmers are smallholders (PND Burundi, 2018), and their limited ability to purchase hybrid maize seed is one of the reasons for the low adoption of hybrid seed.

Hybrid varieties make a lot of money for seed companies. Firstly, because the farmer is obliged to buy seed every year, and secondly, because the farmer is dependent on the seed company, which can then set much higher prices. Subsidies for hybrid maize seed, along with improved distribution channels and extension services, could help smallholders to adopt maize hybrids. The local production of hybrid maize seed will help to reduce retail prices in Burundi, in order to develop local maize production.

D. Towards an Improved Seed System in Burundi

Demand for seeds far exceeds availability, with supply meeting only 13% of current demand. To alleviate these problems, the government has relaunched the seed program by updating seed legislation and the National Seed Plan (PNS). Support for increased seed production has been extended to three levels:

- Stump and pre-basic seed production by ISABU ;
- Production of basic seeds by decentralized extension services (BPEAE) ;
- Production of commercial seeds by groups of multipliers assisted by the Provincial Office for the Environment, Agriculture and Livestock.

To improve seed availability in Burundi, several activities have been undertaken. In 2012, a law on the organization of the seed industry was signed, with the aim of creating a framework to strengthen the development of the seed industry in order to produce sufficient quality agricultural seeds, promote the participation of private operators in the production and marketing of quality seeds, create an institutional system for varietal homologation and seed certification, and develop international cooperation in the seed trade.

The ONCCS (Office National de Control et de Certification des Semences) is active, and private seed producers can operate as associations or individuals. Within this framework, the PSSD project started its activities in 2018 and will be implemented until 2022. With the 2012 Seed Law, private companies are encouraged to invest in the agricultural sector to increase research and variety development and produce sufficient quantities of high-quality certified seed.

VI. CONCLUSION AND RECOMMENDATIONS

The overall aim of this study, entitled "Economic impact of hybrid maize seed on agricultural production and income in Burundi" was to assess the impact of hybrid maize seed adoption on agricultural production, income and food security in Burundian farming households. This study is one of the few to focus on the adoption of hybrid maize seed in Burundi. Empirical results show that the use of hybrid maize leads to increased production and farm income, which in turn improves farmers' welfare. The technical efficiency of maize hybrid adopters is also higher than that of non-adopters. There is a need to ensure that hybrid maize seed is accessible

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to small-scale farmers. The price of hybrid maize seed needs to be reduced by local production, as it is currently mainly imported. However, there are constraints to adoption, notably the unavailability of seed, the high cost of seed, the need for phytosanitary products and the lack of resistance to pests and diseases.

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