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DETERMINANTS OF THE JOINT ADOPTION OF AGRICULTURAL MECHANIZATION EQUIPMENT BY SOYBEAN PRODUCERS IN NORTH BENIN

Kakpo Yssé Stanislas Lokossou[1*], Souléïmane Adeyemi Adekambi[1,2,3], Ibidon Firmin Akpo[1,3] and Jacob Yabi[1,3]

[1]University of Parakou, Doctoral School of Agricultural and Water Sciences (EDSAE).

[2]University Institute of Technology (IUT), Centre for Research in Entrepreneurship-Creation and Innovation (CRECI)

[3]Laboratory for Research in Economic and Social Dynamics (LARDES - UP), University of Parakou, Benin, B.P. 123, Parakou, Benin.

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ABSTRACT

This study analyzes the determinants of the joint adoption of agricultural mechanization equipment (tractor, planter, thresher) by soybean producers in northern Benin. It covers 307 producers from the communes of Nikki and Sinendé. Based on primary data, a Multivariate Probit (MVP) model was estimated. Descriptive statistics reveal that the tractor is the most widely used equipment (75%), followed by the planter (68%) and the thresher (36%). Econometric results indicate a significant complementarity between tractor and planter adoption. Technical training positively influences the adoption of all three technologies, access to rental services and cooperative membership favor tractor and thresher adoption, while education level and soybean cultivation area are positively associated with thresher and planter adoption, respectively. The study recommends strengthening public policies focused on mechanization service provision, farmer training, and cooperative support to accelerate agricultural transformation at the local level.

Keywords: Agricultural mechanization, Multivariate Probit model, Benin, Technology adoption, Soybean.

1. INTRODUCTION

Sub-Saharan Africa (SSA) remains the region of the world characterized by the lowest level of use of agricultural equipment, estimated at about 28 tractors per 1000 ha[1,2]. In West Africa, agricultural activities are still mainly based on human labour and the use of rudimentary hand tools, human energy and animal traction. This labour represents nearly 90% of the agricultural workforce on farms[3]. This predominance limits the scope for sustainable intensification and significant improvements in agricultural productivity[2]. However, sustained population growth, rapid urbanization, increased pressure on food security, labour scarcity due to rural-urban migration, and rising wage costs make it essential to modernize production systems[4]. In this context, agricultural mechanization is defined as the use of instruments and machines ranging from simple hand tools to sophisticated motorized equipment, appears to be a strategic lever for structural transformation of the agricultural sector and improvement of productive performance.

The advantages of mechanization are numerous and documented. It offers considerable potential to increase technical efficiency, reduce the arduousness of work and improve farmers' incomes[5].

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Several studies show that the use of agricultural equipment contributes to increasing yields, reducing post-harvest losses, and improving the food security of rural households[6,7]. Investment in agricultural machinery has made it possible to accelerate agricultural intensification, improve incomes and transform agri-food systems in countries such as India, China, Brazil and Turkey[3]. However, despite these proven benefits, agricultural mechanization in West Africa is severely hampered by a set of constraints. These include low investment (in equipment, infrastructure, training and research), low purchasing power of farmers combined with low prices for agricultural products, as well as difficulties in accessing agricultural credit[8]. In addition, there is a lack of qualified human resources (technicians, specialized managers, tractor drivers, mechanics, blacksmiths) to ensure the efficient use, maintenance, repair and sustainable management of agricultural equipment, the lack of equipment suitable for agricultural operations, the variable quality of imported equipment and difficulties in the supply of spare parts, as well as a general lack of technical skills in terms of mechanization, in particular for agricultural motorization[9,2].

In order to promote mechanization, several initiatives have been implemented by the governments of West African countries, including the importation and distribution of subsidized machinery. In addition, privately led equipment rental services have been developed to allow producers to access equipment without necessarily having to acquire it. Despite these efforts, the adoption rate of mechanization technologies remains low[8,10,11]. For example, it was estimated to be less than 10% in 2016[8]. However, in Benin, Saliou et al.[12] showed that the adoption rate of tractors was about 35% among cotton farmers. These different levels of adoption according to the sectors and the regions, reveal a strong heterogeneity in the use of mechanization technologies. Such variability stipulates the existence of socio-economic, technical and institutional factors that condition the adoption of these mechanization technologies. Understanding the factors that influence the adoption of mechanized equipment has been the subject of much scientific work. Saliou et al.[12] reveal that the farmer's level of education, cultivated area, access to land, access to credit and agroecological zone have a positive influence on the probability of adopting mechanization in cotton production in Benin. In Ondo State, Nigeria, using a logistic regression model applied to maize farmers, Ayodele[13] showed that the main factors influencing the adoption of agricultural machinery are based on a logistic regression model applied to maize farmers. Tchinda[14], in his study on the determinants of threshing machine adoption in Cameroon, shows that the characteristics of the head of household, income, access to credit and the size of the farm explain the use of modern equipment. In Tanzania, tractor adoption is influenced by farm size and the level of wealth of producers[15], while in Ethiopia, combine adoption is determined by the farmer's level of education, access to credit, and cooperative membership[6]. Hassena et al.[16] also show that proximity to rental services, topography, level of education and area under wheat cultivation significantly influence the adoption of harvesting technologies.

However, most of these studies have analyzed the adoption of different agricultural equipment in isolation, using conventional logit or probit estimation methods. Such approaches do not take into account the potential interactions and complementarities between equipment. Recent studies have highlighted significant correlations between decisions to adopt different agricultural equipment[17,4,18]. This suggests that a producer may or may not adopt equipment based on their choices regarding other equipment. This interdependence of adoption decisions remains an underexplored aspect, particularly in the context of West African smallholders.

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This study aims to fill this gap by examining the factors that influence the joint adoption of agricultural equipment by northern soybean farmers in Benin. It contributes to the existing literature on agricultural mechanization in sub-Saharan Africa in several ways. First, and contrary to previous work that analyzed the adoption of different agricultural equipment in isolation using the classic logit or probit models, this study analyzes the joint and interdependent adoption of agricultural equipment used at the different stages of soybean production. Indeed, although this legume plays a decisive role in food and nutrition security in Benin, agricultural operations remain mainly characterized by traditional practices and a strong dependence on manual labour[19]. But soybean farming, like other crops, relies on critical farming operations such as ploughing, sowing and harvesting, which require speed, precision and timing. According to Agbangba et al.[19], these operations are real bottlenecks for producers, especially in contexts of labour constraints and climate variability. In addition, Benin's Strategic Plan for the Development of the Agricultural Sector (PSDSA) explicitly identifies soybeans as a strategic sector, which implies a concentration of public interventions in terms of equipment and support services[20]. As a result, based on the existence of potential complementarities between ploughing, sowing and/or harvesting equipment, the study highlights the fact that producers' adoption decisions are not independent as previously shown, but rather are based on a logic of technological combination. In a context of agricultural mechanization paradox, i.e. institutional attention translated into a concentration of public interventions in terms of equipment and support services but with a still low level of adoption of mechanized equipment in the soybean sector[21], the present study, through a more realistic and systemic analysis, contributes to improving our understanding of the adoption behaviors of smallholder farmers, in particular soybean producers; which is still poorly documented in the West African context.

Secondly, while most studies on the sector in Benin have focused on varietal innovations, technical itineraries and/or product processing in the agri-food sector[22], this study highlights the determinants of the adoption of mechanization agricultural equipment at each stage of soybean production. As a result, it makes it possible to improve knowledge of the factors that promote or hinder the transition to more mechanized production, thus making it possible to identify concrete levers of action likely to accelerate the mechanized transformation of this strategic sector.

1.1 Literature review: agricultural mechanization in Benin

Agricultural production systems in Benin remain largely dominated by the use of hand tools, with a secondary place given to harness farming[21]. According to RGPH4 data, 87.8% of farms use traditional tools, compared to 3.1% that use harness farming, 6.9% that combine traditional tools and harnessing, 0.6% that use motorized equipment and 1.6% that combine traditional tools and mechanical equipment[23]. This structure reflects an overall low level of mechanization of the agricultural sector.

According to the Policy and Strategic Action Plan for the Development of Agricultural Mechanization in Benin (2006), 76% of ploughing operations are carried out manually, 23% by harness farming and only 1% by motorized means[24]. Recent data show that only 12.4% of farms practice mechanization of tillage, while the vast majority of producers remain dependent on hand tools and animal traction[25]. This situation contrasts sharply with the estimated need for equipment, particularly tractors, estimated at 10162 units for the whole country, of which barely 1,003 are available[21]. However, this mechanization deficit does not manifest itself uniformly across agricultural sectors. Indeed, according to Dayou et al.[22], the level of tractor use varies

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greatly from one type of speculation to another: it is particularly high in the production of maize (85.7%) and cotton (68.5%), but remains moderate for sorghum (26.1%) and soybeans (26.4%), and very low for rice (16.8%), cassava (11.8%), groundnuts (7.9%), cowpeas (4.9%) and coconut (1.0%). This variability in the level of mechanization reflects significant differences in the dynamics of intensification and technological integration depending on the crop, and reveals that sectors with high commercial potential such as soybeans are still lagging behind better mechanized crops. This delay is all the more worrying as in areas where soybeans are dominant. In the Agricultural Development Pole 4 (PDA4), the main soybean production basin in northern Benin, the rate of satisfaction of tractor needs is only about 13%[24]. This illustrates a considerable structural deficit in agricultural equipment.

Faced with this observation, the Beninese government has undertaken several initiatives to promote agricultural mechanization. Through the Agricultural Mechanization Development Agency, more than 1,000 tractors of different powers (30, 60 and 80 HP), accompanied by attachments (ploughs, rotary cutters, rotavators, seeders), as well as two-wheel tractors and combine harvesters have been introduced in the last decade, mainly from China and India[26]. In addition, an agricultural tractor assembly plant and several maintenance workshops have been set up to strengthen the technical services offer. In terms of research, the joint efforts of the National Agricultural Research System (NARS) and the Agricultural Mechanization Development Agency have made it possible to develop and disseminate various equipment adapted to local conditions, including weeders and seeders[21]. Progress has also been made in the post-harvest field, with the development of processing equipment for several crops (rice, maize, cassava, soybeans, cowpeas, cashews, etc.), thus contributing to the valorization of agricultural products[26]. In the same dynamic, the creation in 2021 of the National Society for Agricultural Mechanization (SoNaMA) aims to structure and energize the mechanization ecosystem. This structure plays a catalytic role by promoting the development of activities such as the manufacture of spare parts, the provision of decentralized after-sales services, the marketing of equipment, the rental of agricultural equipment and the training of stakeholders.

Despite these institutional and technical advances, the development of agricultural mechanization in Benin continues to face many constraints. These include a lack of control over actual equipment needs, a lack of up-to-date databases on agricultural equipment, a lack of knowledge of innovative technologies (such as no-till), and a lack of information on the performance and adaptability of imported equipment to local agroecological conditions[26]. In addition, there is a low adoption of equipment, a lack of technical training and a lack of qualified human resources.

In this context, soybeans, considered a strategic crop, are facing a low level of mechanization. Essential cropping operations, such as ploughing, sowing and harvesting, require speed and precision, but are still major constraints for producers[19]. This technological deficit contributes to low yields, limits the expansion of cultivated areas and exposes producers to losses related to delays in cultivation operations[27]. In this context, it seems essential to analyze the determining factors of the use of agricultural equipment in the soybean sector in Benin, in order to identify levers of action likely to improve the productivity and competitiveness of this strategic sector.

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2. MATERIALS AND METHODS

2.1 Study environment

The Borgou department was chosen as the study area for several reasons. It is part of the Agricultural Development Pole 4 (PDA 4) which, together with the department of Alibori, makes it the soybean basin in Benin. This pole is an agroecological zone prioritized by public policies for the promotion of soybeans as a locomotive cash crop. Thus, public policies have directed targeted investments in agricultural equipment and support services for producers. This concentration of institutional interventions creates the conditions for variability in levels of adoption to allow for rigorous econometric analysis. In addition, with these pedoclimatic conditions, including a tropical climate and ferruginous soils, the region offers a high agronomic potential for legumes. This zone represents the second largest soybean production zone with 150,000 tonnes produced annually on average over the last 5 years[28]. But the full potential is not yet extinguished because of the low use of agricultural equipment in the production phases, especially ploughing, sowing and harvesting[19]. Mastering the factors that can reduce the use of time-consuming manual practices and thus promote the massive use of agricultural equipment can help increase the productivity of this crop in this area.

Geographically, the department of Borgou is located between 9°00'00" and 12°00'00" north latitude and between 1°30'00" and 3°00'00" east longitude. It covers an estimated area of 83,723 km², or 72% of the national territory (114,723 km²). The department includes eight municipalities. The study targeted two of them: the municipality of Nikki and the municipality of Sinendé. The municipality of Nikki is located between 9°56'24" and 9°57' north latitude and between 3°12'38" and 3°13' east longitude. The commune of Sinendé is located between 10°20'41" and 10°34' north latitude and between 2°22'45" and 2°38' east longitude.

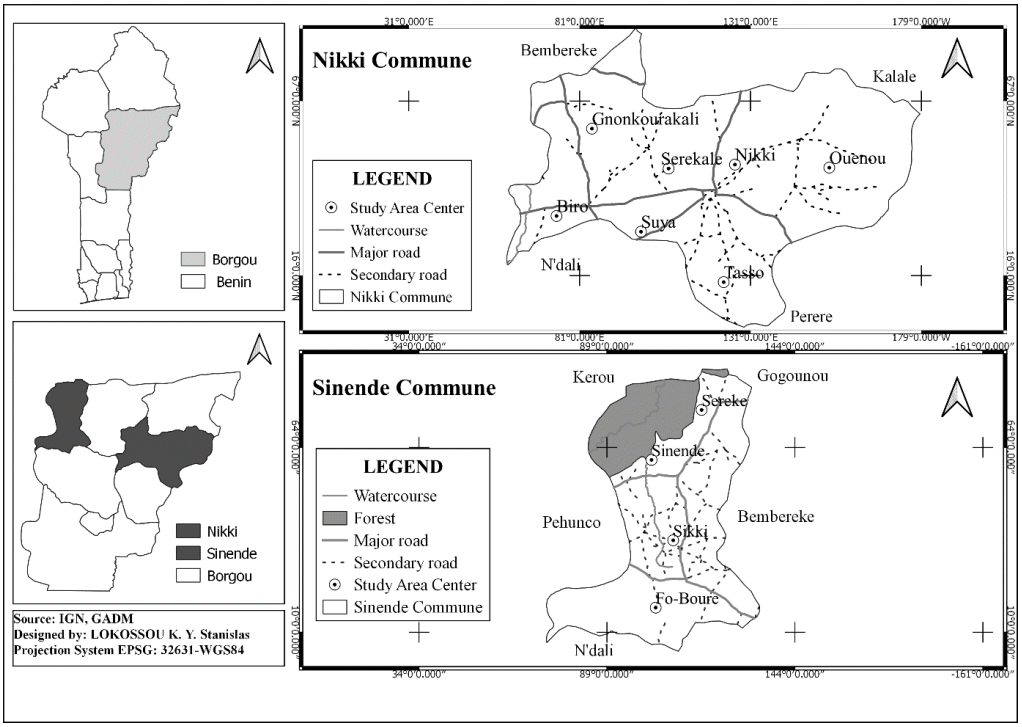


Figure 1: Map of the study environment

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2.2 Sampling

To ensure regional representativeness of soybean producers, a multi-stage cross-sectional sampling plan has been adopted. Initially, the eight municipalities of Borgou were classified into two categories taking into account the level of production in 2024. With an average production of 21,187 tonnes, the municipalities with a production below this value were the municipalities with low production against the municipalities with higher-than-average production. A random choice of a municipality was made within each category. Thus, the communes of Nikki (38,086 tonnes) and Sinendé (20,443 tonnes) have been selected as the commune with high production and the commune with low production respectively. Then, a simple random sampling made it possible to select ten villages in each of the two communes. The minimum sample size was determined using the formula based on the method proposed by Cochran (1977), adapted to finite populations.

The formula used is as follows:

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

$$n_{adj} = \frac{n}{1+\frac{n-1}{N}} \quad (2)$$

Where Z = 1.96 corresponds to the 95% confidence level, p = 0.5 is the estimated proportion (used conservatively to maximize size), e = 0.05 is the tolerated margin of error, and N is the total size of the target population. The sampling frame for all producers in the 20 study villages consisted of 1,200 producers. Applying the formula, the required sample size was 291 producers. To reach saturation, this size was increased to 310 producers, i.e. 155 producers per municipality, to ensure sufficient statistical power for econometric modelling. However, 307 producers were actually surveyed with 152 in the commune of Nikki and 155 in the commune of Sinendé. This difference in Nikki can be explained by field constraints related to the quality and completeness of the data collected.

2.3 Data collection

Primary data were collected through individual, structured interviews conducted face-to-face by interviewers fluent in local languages (Bariba, Dendi, Peulh). The questionnaire, pre-tested and adapted to the local context, collected detailed information on household socio-demographic characteristics, farm structure, cultivation practices, use of agricultural equipment and access to institutional support services during the 2024-2025 agricultural season.

2.4 Analytical framework and model specification

The decision to adopt different agricultural machinery is part of a process where technological choices are interdependent. A producer may decide to adopt a tractor, a seeder and a winnowing thresher simultaneously, sequentially or in partial combination[29]. Estimating separate univariate models (such as separate Logit or Probit for each piece of equipment) would ignore the potential correlation between the error terms of these decisions, leading to biased and inefficient estimates. This correlation is often the result of unobserved factors (intrinsic managerial skills, micro-local soil fertility, risk appetite) that jointly influence several choices[30].

To examine this dynamic of complementarity or substitutability between equipment, we use a Multivariate Probit (MVP) model. The MVP postulates J a system of equations (where $j = 1, 2, 3$ respectively represent the adoption of the tractor, the seeder, and the threshing-

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winnower). The latent variable Y_{ij}^{*} capturing the expected utility of the producer's i adoption of the equipment j is expressed by:

$$Y_{ij}^{*} = \alpha_j' X_{ij} + \mu_{ij},; \quad j = 1,2,3 \ (3)$$

The observable decision Y_{ij} takes the value 1 if $Y_{ij}^{*} > 0$, and 0 otherwise. X_{ij} represents the set of explanatory variables and α_j parameters. The fundamental assumption of the MVP is based on the joint distribution of error terms μ_{ij}. These follow a multivariate normal distribution of zero mean and symmetric Σ variance-covariance matrix:

$$\Sigma = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix} (4)$$

The off-diagonal correlation coefficients (ρ_{jk}) measure the unobserved interdependence between equipment j and equipment k adoption. A positive ρ_{jk} and statistically significant indicates complementarity between two technologies, justifying the interest of their joint promotion. Conversely, a negative coefficient suggests substitutability. The system of equations is estimated by the Simulated Maximum Likelihood (SML) method using the GHK (Geweke-Hajivassiliou-Keane) algorithm adapted to the evaluation of multiple integrals[31]. The overall relevance of the MVP approach is validated by Wald's test on the null hypothesis of joint independence of error terms ($H_0: \rho_{21} = \rho_{31} = \rho_{32} = 0$).

2.5 Description of the variables in the model

2.5.1 Dependent variable

The main variable explained in this study is the *joint adoption of agricultural mechanization technologies*. Unlike the isolated adoption of a single piece of equipment, joint adoption generates operational synergies that maximize productivity. This variable is binary: it takes the value of 1 if the producer uses mechanization for the three critical stages of the technical itinerary (land preparation by tractor, mechanical seeding, and post-harvest treatment via the thresher-winnower), and 0 in the case of partial or no adoption.

2.5.2 Explanatory variables

In line with the theory of innovation adoption and the work of Suvedi et al.[32], we postulate that access to services reduces information asymmetry. Variables include: access to agricultural credit (binary), frequency of visits by extension agents (continuous), receipt of technical training (binary), and support by NGOs or state projects. Drawing on the empirical literature on the economics of mechanization[33,34], the model controls for farm heterogeneity via sociodemographic (age, education level, household size), structural (area sown with soybeans, agricultural experience) and social integration (membership of a cooperative) variables.

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Table 1: Description of the independent variables included in the MVP model.

Variables	Descriptions	Terms and conditions
Age	This is the age of the soybean producer expressed in number of years	Discontinuous variable
Instruction	Represents the producer's access to formal education	Binary variable (1 = Yes, 0 = No)
Technical Training	It is the participation of the producer in training on mechanization	Binary variable (1 = Yes, 0 = No)
Co-operative membership	Represents the producer's membership in a cooperative	Binary variable (1 = Yes, 0 = No)
Rental	This is the producer's access to agricultural equipment via rental	Binary variable (1 = Yes, 0 = No)
Credit	It is a question of producer's access to credit	Binary variable (1 = Yes, 0 = No)
Soybean Area	Represents the area sown to soybeans by the producer	Continuous variable

3. RESULTS

3.1 Socio-demographic characteristics of soybean producers

The results presented in Table 2 show that the average age of producers is relatively similar between non-adopters and adopters, regardless of the technology considered. In contrast, household size shows a statistically significant difference at the 1% level. Adopters, especially those using tractors, seeders and threshers, are mostly from larger households (11 people) compared to non-adopters (10 people). Similarly, the number of agricultural workers varies significantly between groups. Adoptive producers generally have a larger agricultural workforce, especially tractor adopters (9 people on average). Regarding the sex variable, the results reveal a statistically significant difference at the 5% threshold, with a more pronounced male predominance among adopters than among non-adopters. In addition, marital status is also significantly associated with adoption. Married producers are in the vast majority of adopters, especially for technologies such as tractors, seeders and threshers, unlike single people who are proportionally less represented (9.77%). Finally, educational attainment does not show a statistically significant difference between groups, although there is a relatively balanced distribution between educated and uneducated producers.

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Table 2: Socio-demographic characteristics of soybean producers

Variables		Non-adopters	Adopters Tractors	Adopters Seed drill	Thresher adopters	Total	p-value
Age		42 (9.52)	42.48 (8.41)	42.18 (8.67)	41.01 (9.54)	41.78 (9.30)	0.11
Household size		10.35 (4.83)	11.31 (4.58)	11.27 (4.51)	11.20 (3.85)	10.63 (4.62)	0.001
Number of agricultural workers		8.33 (4.22)	9.27 (4.04)	7.42 (4.27)	8.77 (3.25)	8.51 (4.02)	0.001
Gender	Male	27 (81.82%)	35 (85.37%)	117 (95.12%)	102 (92.73%)	281 (91.53%)	0.04
	Female	6 (18.18%)	6 (14.63%)	6 (4.88%)	8 (7.27%)	26 (8.47%)	
Marital status	Single	6 (18.18%)	5 (12.20%)	10 (8.13%)	9 (8.18%)	30 (9.77%)	0.001
	Married	27 (81.82%)	35 (85.37%)	113 (91.17%)	97 (88.18%)	272 (88.60%)	
	Divorced / Separated	0	1 (2.44%)	0	0	1 (0.33%)	
	Widow	0	0	0	4 (3.64%)	4 (1.30%)	
Instruction	No	22 (66.67%)	29 (70.73%)	95 (77.24%)	54 (49.09%)	200 (65.15%)	0.18
	Yes	11 (33.33%)	12 (29.27)	28 (22.76%)	56 (50.91%)	107 (34.85%)	

3.2 Soybean farmers' access to cooperatives and institutional services

The results presented in Table 3 show that the majority of producers who are members of co-operatives are found among the adopters, particularly those using the thresher (44.32%) and the planter (41.62%), while non-adopters represent a small proportion (7.57%). There was no statistically significant difference in access to credit between the categories of adopters and non-adopters. For access to agricultural extension services, the results indicate a statistically significant relationship at the 1% level. The majority of producers with access to these services are represented among the adopters, particularly for threshers (39.91%) and seeders (39.46%). In addition, institutional support, although benefiting a relatively small proportion of producers, shows a highly significant effect on adoption. The beneficiaries of this support are mainly concentrated among threshing machine adopters (66.67%). A significant proportion of trained

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producers are found among adopters, particularly for threshers (54%) and seeders (37%), compared to only 1% among non-adopters.

Table 3: Access to institutional support services by co-adoption of mechanization technologies

Variables	Non-adopters	Tractor adopters	Adopters of seed drills	Thresher adopters	Total	p-value
Membership in a co-operative	14 (7.57%)	12 (6.49%)	77 (41.62%)	82 (44.32%)	185 (100%)	0.001
Access to credits	19 (8.92%)	26 (12.21%)	87 (40.85%)	81 (38.03%)	213 (100%)	0.27
Access to extension services	19 (8.52%)	27 (12.11%)	88 (39.46%)	89 (39.91%)	223 (100%)	0.03
Institutional support	2 (5.13%)	2 (5.13%)	9 (23.08%)	26 (66.67%)	39 (100%)	0.001
Access to technical training	1 (1%)	8 (8%)	37 (37%)	54 (54%)	100 (100%)	0.001

3.3 Level of use of agricultural mechanization equipment in soybean production

Figure 2 shows the level of adoption of agricultural mechanization equipment as well as the different combinations of equipment used by soybean producers. It indicates that the tractor is the most adopted equipment with 75% of producers, followed by the seeder with 68%. The winnowing thresher is less adopted with a proportion of 36% of producers. When it comes to joint adoption of equipment, the tractor and seeder combination is the most prevalent with 83.33% of producers. It is followed by the tractor and thresher combination, which concerns 84.55% of producers. It should be noted that the combination of seed drill and thresher is observed in 79.09% of producers. In addition, the analysis of the number of equipment adopted shows that 39% of producers use two pieces of agricultural equipment, compared to 25% who use three pieces of equipment and 24% who use only one piece of equipment.

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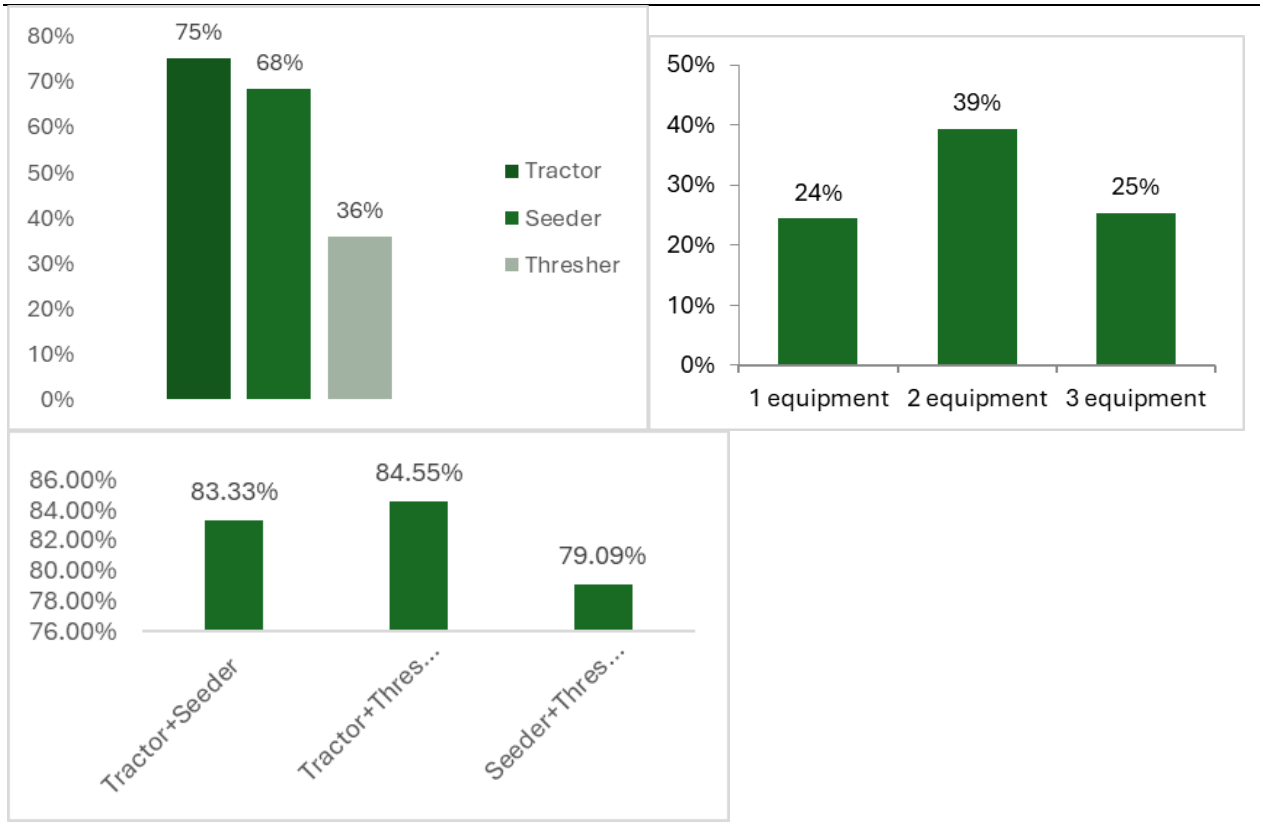


Figure 2 : Level of use of agricultural equipment by soybean producers

3.4 Determinants of the joint adoption of agricultural equipment in soybean production

3.4.1 Analysis and interpretation of the estimation model

The results from the estimation of the multivariate probit model (MVP) reveal that the entire model is overall significant at the 1% level. Thus, the decision to adopt one piece of equipment is therefore determined by another piece of equipment.

The analysis of the correlations between the residuals of the equations (rho) makes it possible to assess the degree of interdependence between the adoption decisions (Table 4). Only the correlation between tractor and seeder adoption (rho21 = 0.2622; p = 0.012) is statistically significant at the 5% level. This positive and significant result indicates that the decisions to adopt these two machines are complementary. Thus, farmers who use a tractor also tend to adopt a seeder, and vice versa. However, the correlations between tractor and winnower adoption and between planter and thresher are not statistically significant. Nevertheless, the likelihood ratio test ($chi^2(3) = 6.88$; p = 0.076) indicates an overall trend towards interdependence between the three equations.

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Table 4: Correlations of error terms between MVP equations

Equations	RHO	Coeff.	Std. err.	z	P > |z|
Tractor & Seeder (rho21)	0.2622	0.2685	0.1074	2.50	0.012**
Tractor & Thresher (rho31)	0.0955	0.0958	0.1063	0.90	0.367
Seed Drill & Thresher (rho32)	0.0589	0.0590	0.1056	0.57	0.578

*Note: ** significant at 5%*

3.4.2 Results of estimating the determinants of joint adoption of agricultural equipment

The results of the multivariate probit model highlight several factors influencing the adoption of agricultural mechanization equipment, including tractor, seeder, and thresher. Among the explanatory variables, training in the use of agricultural machinery appears to be the most consistent determinant of the adoption of the three pieces of equipment. It has a positive and statistically significant effect on the adoption of tractors, seeders and threshers. This result shows that producers who have benefited from technical support on the various equipment are more willing to adopt them. The training improves farmers' technical knowledge, strengthens their ability to understand the benefits of innovations, and facilitates their use in production. On the other hand, the variable access to equipment rental services only influences the adoption of the tractor and the winnowing thresher. This effect is positive and significant at the 1% level. The availability of rental services reduces the financial constraints associated with the purchase of this equipment, which is often expensive, and thus offers producers with limited resources the opportunity to access this equipment.

The level of education has a positive and highly significant effect on the adoption of the thresher at the 1% threshold. Educated producers have a greater ability to understand the technical and economic benefits of post-harvest mechanization. In addition, membership in a cooperative has a positive influence on the adoption of tractors and threshers at the 10% threshold and seeders at the 5% threshold. Cooperatives are indeed favourable frameworks for the dissemination of information, the sharing of experiences between producers and collective access to agricultural equipment. Finally, the area under soybean cultivation has a positive effect on the adoption of certain equipment. It is marginally significant for the seeder and significant at the 5% threshold for the thresher. This result indicates that producers with larger acreages have a greater incentive to mechanize certain farming operations in order to reduce labour costs, improve work efficiency and manage larger production volumes.

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Table 5 : Determinants of Agricultural Machinery Adoption (Probit Multivariate)

Variable	Tractor		Seed drill		Thresher	
	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Age	0.0177*	0.0092	0.0077	0.0087	-0.0114	0.0095
Instruction	-0.0537	0.1775	0.0746	0.1678	0.5408***	0.1749
Technical Training	0.4958***	0.1898	0.4664***	0.1733	0.6491***	0.1736
Co-operative membership	0.3008*	0.1783	0.3722**	0.1696	0.3322*	0.1846
Rental	0.5284***	0.1749	0.2214	0.1598	1.0281***	0.1672
Credit	0.2212	0.1825	0.0865	0.1752	0.0608	0.1935
Soybean area	-0.0258	0.0622	0.1328*	0.0672	0.1368**	0.0584
Constant	-0.6080	0.4415	-0.7699*	0.4304	-1.4873***	0.4522
N observations	307					
Wald chi2(21)	124.37***					
Log likelihood	- 481.2277					
Prob > chi2	0.0000					

*Note: *** significant at 1%, ** significant at 5%, * significant at 10%, coeff.= coefficient and Std. Err.= Standard Error*

4. DISCUSSION

The results of this study are in line with the *Random Utility Theory* (RUT) formalized by McFadden[35] and mobilized in the literature on the adoption of agricultural innovations[32]. According to this framework, a rational producer adopts a technology if the expected net benefit of adoption exceeds that of non-adoption. The results obtained from the MVP estimate confirm this logic. Indeed, formal instruction increases the producer's ability to correctly assess the risks as well as the expected economic benefits of mechanization[36]. This mechanism refers directly to the reduction of information asymmetry postulated by Rogers' theory of diffusion of innovations[37]. According to this theory, the likelihood of adoption increases with increasing levels of exposure to information and the cognitive ability to process it. Technical training on the use of agricultural machinery plays this role in this context. It increases the intelligibility of the equipment and reinforces the perception of its relative advantage. The effect of access to rental services can be interpreted in the light of the theory of liquidity constraints developed in the work of Feder et al. This theory establishes that capital poverty is a structural barrier to the adoption of expensive technologies. The rental service reduces this barrier by decoupling access to technology from ownership of the equipment. Finally, the positive effect of membership in a cooperative on the adoption of the planter mobilizes the theory of social capital[38]. This theory

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confirms that social networks reduce the transaction costs related to the acquisition of information and facilitate the pooling of resources.

The main contribution of this study was the simultaneous modelling of the adoption decisions of three different pieces of equipment. The MVP validates the relevance of this approach. The correlation coefficient between the residues of the tractor and seeder equations is positive and statistically significant ($\rho_{21} = 0.262$; $p = 0.012$). This result provides information on the existence of a technological complementarity between these two facilities. Adoption decisions are therefore not independent of each other. Estimating separate equations would have produced biased parameters and incorrect inferences. This complementarity between mechanised ploughing and mechanical sowing reflects an agronomic logic according to which tractor-based soil preparation creates the technical conditions necessary for precision sowing. On the other hand, the correlations between the winnower thresher and the other two pieces of equipment are not significant ($\rho_{31} = 0.095$; $p = 0.367$; $\rho_{32} = 0.058$; $p = 0.578$). The thresher obeys a dynamic of independent adoption. Its low adoption rate and its post-harvest positioning in the production cycle could explain this independence of farmers' decision-making.

In terms of individual determinants, the MVP reveals that technical training is the only variable that has a positive and significant effect on the adoption of all three devices simultaneously. Access to rental services positively influences the adoption of tractor ($\beta = 0.5284$; $p < 0.01$) and winnower thresher ($\beta = 1.0281$; $p < 0.01$) but is not significant for the planter. Membership of a cooperative influenced the adoption of the seeder ($\beta = 0.221$; $p < 0.05$). The area under cultivation has a positive effect on the adoption of the seeder and thresher. These results are in line with the structural specificities of the soybean sector in Benin. First, in the current context of Benin, the soybean sector occupies a strategic position due to the growing demand from regional and international markets[39]. It is precisely to meet this demand that the Benin Investment and Industry Promotion Company (SIPI-Benin) was set up in the Glo-Djigbé industrial zone. This boom explains the strong interest of producers in the cultivation of soybeans in Borgou. It should be noted that soybeans are in direct competition with cotton, which has historically been better structured and highly mechanized. Since the same producers often practice both types of speculation, the dynamics of equipment adoption observed in soybeans may be influenced by the experiences gained in the cotton sector. In this context, technical training appears to be decisive, as it allows producers to transfer and adapt their skills towards a culture that is being modernized. In addition, access to rental services reflects the capital constraints specific to Beninese farms, limiting the direct acquisition of expensive equipment[8]. The effect of cooperatives can be explained by their role in market access and inputs, particularly in a soybean sector that is increasingly organized around producer groups, thus facilitating the adoption of the seeder. Finally, the effect of surface area reflects economies of scale, with producers who are more committed to commercial logics being more inclined to mechanize to meet the productivity and schedule requirements imposed by the market

The results of this study provide information that should be compared with previous work in order to identify dissimilarities and nuances for a better understanding. The positive and cross-cutting effect of technical training on the adoption of the three pieces of equipment is consistent with the results of Abebe et al.[6] in Ethiopia. These authors show that access to capacity building programs significantly increases the likelihood of adopting agricultural machinery. Quan and Doluschitz[40] establish in China that technical assistance is a central determinant of adoption among small-scale operators. The present study extends these results in a West African context

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characterized by a general low level of education. The significant effect of rental services on tractor and thresher adoption is documented in several similar contexts. Tilahun et al.[4] in Ethiopia identify access to rental services as the most important driver of the adoption of mechanization services. Van Loon et al.[41] confirm this mechanism in several sub-Saharan African countries and establish that *Mechanization Service Provider Models* are the central lever for the diffusion of agricultural technologies in a low-cap context. Similarly, the AMSEC program in Ghana was designed precisely to overcome this barrier by promoting private service centers to make mechanization affordable at the local level[42]. Regarding the area studied, it should be noted that rental services are set up by companies such as SoNaMa. Also, other producers with the machines provide rental services to other producers. These initiatives are gaining momentum and are having a significant effect on the adoption of agricultural equipment. However, the fact that this same effect is not significant for the planter is explained by the relatively low cost of this equipment in the area. Its direct acquisition is more accessible than that of the tractor or thresher. In addition, the tractor-seeder complementarity highlighted by the MVP is in line with the work of Kassie et al.[29] on the simultaneous adoption of agricultural practices in Tanzania. These authors demonstrate that decisions to adopt related technologies are structurally interdependent and that their joint modelling is essential for the validity of the estimates. Teklewold et al.[30] confirm this same interdependence in the Ethiopian context. The dominant adoption of tractors (75%) and seeders (68%) compared to low adoption of winnowers (36%) confirms the sequential mechanization trajectory described by Pingali[43]. This author establishes that in developing countries, mechanization systematically begins with energy-intensive tasks. Post-harvest operations are only mechanized at a later stage. Lu et al.[44] confirm this pattern in China. The positive effect of crop area on planter and winnowing adoption is documented by Quan and Doluschitz[40]. These authors show that economies of scale justify the adoption of precision equipment beyond a certain threshold of exploited area. Below this threshold, the marginal cost of mechanization exceeds the expected benefit. Membership in a co-operative has a positive effect on the adoption of the planter. This result is in line with those of Abebe et al.[6] who establish that social capital facilitates the diffusion of innovations in rural agrarian systems in sub-Saharan Africa. These authors show that experienced producers have a higher propensity to adopt mechanization to compensate for the arduousness of manual work accumulated over time.

5. CONCLUSION AND RECOMMENDATION

The ambition to transform West African agriculture, and particularly the soybean sector in Benin, undeniably requires a supervised modernization of production tools. This study has empirically demonstrated that the adoption of mechanization technologies (tractor, seeder, threshing-winnow) in Northern Benin is supported by various factors. It is intimately linked to the ability of farmers to educate themselves, to form cooperatives and, above all, to access machinery rental services.

The results of the Probit Multivariate model highlight that farmers perceive soil preparation and sowing operations as an inseparable technological block, while post-harvest mechanization (threshing) is still struggling to gain traction. The political message that follows from this is that it is enough to subsidise the purchase of tractors in isolation. The government and development partners need to invest in human capital (technical training), structure the market for mechanized service providers, and facilitate access to credit for local agricultural entrepreneurs. It is at this

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price that Beninese agriculture will be able to meet the challenges of food security, compensate for the scarcity of rural labor and guarantee decent incomes for producers.

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