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Using a Whole-farm modelling approach to assess changes in farming systems with the use of mechanization tools and the adoption of high yielding maize varieties under uncertainty in Northern Benin

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Abstract

Farmers will adopt new agricultural technologies and other policy instruments if they fit into their resource endowments, objectives, goals, and risk aversion strategies. This study examines the effects of high-yielding maize varieties and the use of machineries on the production, income, crop mixtures, and demand for production resources in two farms and farm household typologies in the northern cotton growing belt of Benin Republic. The role of whole-farm modelling in agricultural technology and policy instruments evaluation is discussed. Data on high yielding maize varieties and machinery use in production activities were collected from the data repository of the National Agriculture Research Institute of Benin (INRAB), Universities in Benin and relevant literature. The secondary dataset on farms and farm households were subjected to the Target MOTAD models, constructed for Type 1 and type 3 households. The models were run with and without the high-yielding maize varieties and the machinery (tractor). Results indicate that the introduction of new varieties, machineries raised and farm household income in the two typologies had varying effects on land allocation for the crops.

Key Words:

Whole-farm modelling approach; high-yielding maize varieties; use of the machineries; Target MOTAD model, Resource allocation, farm typologies and farm household.

Introduction

Agriculture remains the core sector of Benin's economy. The agricultural sector represents about 70% of the active population, contributes around 33% of gross domestic product (GDP), provides about 75% of export earnings, 15% of total revenue and employment for about 70% of the labor force (INSAE, 2015). Therefore, the promotion of the agricultural sector is considered a priority to accelerate national economic growth and thus contribute effectively to the reduction of poverty (MAEP, 2016; MAEP, 2014). In fact, poverty is more pronounced in the rural areas, despite the fact that the national economy is based on it (MAEP, 2015).

Like in other African countries, agriculture is dominated by small family holdings oriented towards polyculture often associated with small livestock (poultry, small ruminants) (Gafsi et al., 2007, Adegbola et al., 2017a). More than elsewhere, family holding is predominant in Africa, relying mainly on family labor FAO (2014). Africa has 33 million holdings under two hectares that account for 80% of all holdings (NEPAD, 2013). In sub-Saharan Africa (SSA), it accounts for more than 75% of agricultural holdings (Agricultural Households) and provides the essential of rural incomes (Alpha and Castellanet, 2007). The same is true of the Beninese agricultural sector, whose number of small family agricultural holdings are estimated at about 550,000 (MAEP, 2011). On average, the area of agricultural holdings is estimated at 1.7 hectare with an average of seven household's members. About 34% of holdings cover less than one hectare and only 5% of these holdings are in the south and 20% in northern Benin cover more than five hectares (MAEP, 2015).

Family Agricultural Households play an important role in food security and rural development in most developing countries (Schut et al., 2016). Indeed, they provide up to 80% of food production in Asia and Sub-Saharan Africa. Agricultural Households can thus contribute to eliminating hunger and malnutrition with enhanced interventions (FAO, 2014). Various governments r in Benin have shown a growing interest in the promotion of agricultural holdings. The Strategic Plan for the Revival of the Agricultural Sector (PSRSA 2011-2015), developed and adopted by the Benin government placed emphasis on the professionalization of farming; to this end, many interventions were made to increase access to production assets including agricultural technologies. However, these technologies are yet to yield the desired scale of success at the smallholder's level; some of the technologies are only adopted by a few, while others are outrightly rejected.

Actually, the performance of the agricultural sector has been particularly weak, and the production is not always sufficient to satisfy all the diversified demand for agricultural products in the country, which is also a growth trajectory in the last ten years. The income and productivity of the agricultural sector are low, and the productivity of the labor force is only partially valued (MAEP, 2016a). The low productivity is linked to the use of rudimentary tools and a low rate of adoption of improved seeds, low mechanization, rudimentary processing equipment, non-control of water, poor organization of specific sector, the lack of technical supervision, the lack of infrastructure, the low funding of production activities and the low level of gender mainstreaming in development policies (MAEP, 2015, MAEP/PSDSA, 2016b). In addition, the family holdings are highly exposed to national agricultural policy reforms. Policies to increase labor productivity are often lacking or are sometimes limited to the simple distribution of tractors (Gafsi, 2007). The agricultural sector is also exposed to climate variability and change and other risks inherent in agriculture (Adegbola et al., 2017a). These various difficulties do not enable to increase agricultural productivity and ensure food security, making agricultural products highly competitive (MAEP, 2016a). This also raises the question of public policies vis-à-vis the sector and especially agricultural holdings. Since the intervention of the Beninese government, the agricultural sector has a major role in achieving the objectives of agricultural development in Benin. This is achieved through the many agricultural policy instruments put in place and to meet these challenges mentioned above, sustained attention must be given to the generation and diffusion of technological innovations and agricultural mechanization tools, with respect to the quality standards and the sustainable management of natural resources. Since increasing agricultural productivity is needed to improve food security in African countries, this requires intensification of the agricultural system through the use of new and more productive technologies (Awotide et al., 2013).

Concretely, there are encouraging signs for a better consideration of agricultural holdings by public policies in Benin. In this sense, several technologies have been developed and implemented by the National Agricultural Research System of Benin (NARS) and some projects and development programs in the last twenty years (Adegbola et al., 2016, 2017a). In order to highlight the research achievements generated by the NARS, two studies were conducted in 2015 and 2016 with the financial support of the Forum for Agricultural Research in Africa (FARA). The results of these studies highlighted several promising agricultural technologies in the fields of crop, animal and fishery production on one hand and in the field of processing and storage on the other hand (Adegbola et al., 2016; Adegbola et al., 2017a). These agricultural technologies have among other intent to affect positively agricultural households. However, it is essential to conduct a study before the large-scale extension phase to understand whether the promising agricultural technologies can be substituted for the traditional (current) agricultural technologies within a whole-farm plan context and, if so, what are the likely economic benefit implications for farmers.

Several economic impact appraisals of agricultural technologies on productivity, profitability, welfare, food security and poverty indicators were carried out in Benin. These studies focused on analyzing determinants of adoption and then evaluating economic impacts (Adekambi, 2005; Lokossou, 2011). Only a few of those studies applied an ex-ante assessment (Donfosou et al., 2007). Furthermore, most of them ignore the potential risks, which often lead to unacceptable results for smallholders or does not reflect current decisions. Especially when smallholders are risk-averse like in developing countries (Hazell and Norton 1986, Adegbola, 1997) there is the need to integrate risk in the modelling of agricultural holdings justified by the fact that smallholders face risks related to price, yield and resource that make their income unstable from year to year (Hazell and Norton, 1986 ; Adegbola, 1997). In this context, this study proposes to make an ex-ante evaluation of the promising high-yielding maize varieties in Benin. The salient objective of this study was to develop a decision-making tool for assessing changes in farming systems with the use of mechanization tools and the adoption of new agricultural technologies under uncertainty in Northern Benin. Yiridoe et al., (2006); Torkamani (2005) reported that an optimal whole farm planning model as used in the in this study is useful in anticipating the impact of the prospective technologies in the real environment and propose effective measures for their adoption. The study focuses on FARA commodities such as rice, soybean, small ruminants, and poultry. In addition, cotton, and maize were selected as these crops appear as main crops in the cotton zone of Northern Benin (Adegbola et al., 2017). The smallholders' decision to use a prospective technology is guided by his rationality, considering the political and socio-economic environment.

The main risk in Benin are price and production risks, i.e. objective function coefficient risks, there is a tradeoff between risk and return (Adegbola, 1997). Therefore, risk programming models have attracted attention. Among them MOTAD (Minization of Total Absolute Deviation) and Target-MOTAD models have been applied more than others for their flexibility (Börner, 2006). The generalized MOTAD model developed by Hazell (1971) uses a linear approximation of the expected income variability to represent risk. In addition, this method handles risk by absolute standard deviation, where parameters are supposed unpredictable. Unlike generalized MOTAD, the target-MOTAD integrates an additional constraint which sets a target level on the total income (Hazell et Norton, 1986; Zia, 1992; Adegbola, 1997). In this study, smallholders' behavior pattern in Benin was investigated using the Target-MOTAD developed by Tauer (1983). Target-MOTAD was employed here, not only because this is the most widely applied technique for these types of risk, but also because it has a linear objective function and linear constraints. The study will provide useful information to researchers, policy-makers, extension services, and smallholders. This would help to better guide agricultural technologies generation efforts in Benin.

The remainder of the report is organized as follows: Section two presents the materials and methods used in this study. Results are exposed and discussed in the third section. Conclusions and policy implications are presented in the last section.

Materials and Methods

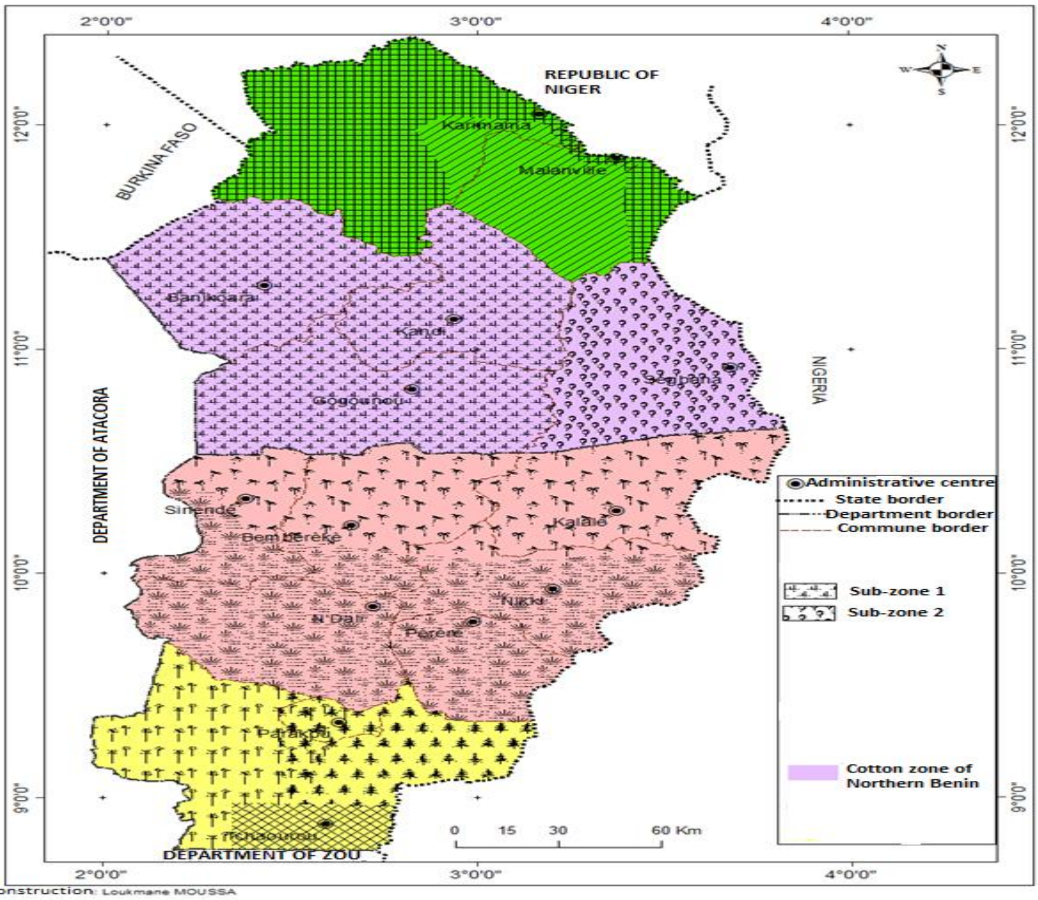
Materials

Study area

Among the eight agro-ecological zones of Benin, the cotton zone of Northern Benin, generally termed as agroecological zone two (AEZ2) was selected as the study area. This zone enjoys natural and favorable conditions to crop and animal production. The designation of this agro-ecological zone comes from its main source of income, cotton. Based on a characterization process, Adegbola et al. (2017) divided the agroecological zone two in two agroecological sub homogenous zones. From a Sudanese-type climate, marked by a rainy season (May to

November) and a dry season (November to April), it records during the last 5 years an average annual rainfall of 863.61 mm of water with 46 (± 6.68) days of rain (Adam and Boko, 1993). There are tropical ferruginous soils and little concretized with a variable agronomic characteristic (Viennot, 1978, Youssouf and Lawani, 2000). The vegetation is dominated by a tree shrub savannah strongly degraded by humans. There are thorny trees such as Acacia siberiana and Vitelaria paradoxa (Adomou, 2005). The vegetative growth period is between 140 and 180 days and the average altitude in is around 493 m.

According to the RGPH 4 (General census of population and households) in 2013, the cumulative population of the four surveyed municipal areas is estimated at 633,365 inhabitants, including 317,612 women, i.e. 50.14% of the total (INSAE, 2015 and 2016). Despite the emigration of the youth toward cities (Parakou, Porto-Novo and Cotonou in particular) and Nigeria, this population has a relatively high growth rate of around 4.6% between 2002 and 2013 compared to 4.08% between 1992 and 2002 compared to the statistics from RGPH 2, 3 and 4. The region is mainly populated with the Boko, Peulhs, Boo, Baatonou, Gando, Mokole and Dendi socio-cultural and socio-linguistic groups (INSAE, 2003).



Construction: Loukmane MOUSSA

Figure 1: Location of the Cotton Zone of Northern Benin (AEZ2)

Source: Adegbola et *al*., 2017

Farming systems in the cotton zone of Northern Benin

The cotton zone of Northern Benin remains the leading producer of cotton in Benin. In addition to cotton production, animal production, forest exploitation and trade are also important activities. In this area, maize appears to be the major grown cereal whiles a small area is devoted to millet. The most commonly grown staple crops are maize (main cereal grown), sorghum, yam, rice, cowpea and peanut. Perennial crops are mango, teak and cashew (INSAE, 2002). Slash-and-burn is the most common technique of preparing fields for the next crops. Partition ridging and earthing up are the plowing methods. Rotational, mono cropping, intercropping and/or mixed cropping are practiced. Cotton is often grown at the head of rotation. Several types of mixed crop arrangements are identified (maize-sorghum, maize-cassava-cowpea, etc.). The staple crops are often maize and cowpea. Basic crops are associated with other secondary crops including sorghum, yams, cassava, peanut and millet. Mono cropping is generally practiced for cotton, maize, soybean, sorghum and yam. Food production is primarily intended for the households' consumption. However, maize, okra and chili are also produced for the market (Adegbola et al., 2017).

The major crops contributing to the income and to food and nutritional security in the cotton zone of Northern Benin are cotton, maize, soya, rice and cassava (Agbangba et al. 2018). In fact, in all villages of PDA2 where the surveys were carried out, producers declared that maize is the first crop that contributes substantially both to the income and food security of the populations, followed by cassava, soya and rice. Cotton is the major cash crop that generates cash for producers in the cotton zone of Northern Benin. Furthermore, Farm households in the cotton zone of Northern Benin also process agricultural products. Gari made from cassava processing is the first product that contributes the most to the revenues of farm households, followed by groundnut oil. In other respects, gari, soya cheese and groundnut oil are by order of importance the three processed products that contribute to the diet of farm households (Agbangba et al. 2017).

In the livestock system, beef, sheep and goat fattening and apiculture are the main animal production activities. Fishing and hunting are marginal, but they still exist. Animal species reared are poultry, small ruminants, pigs and cattle. Poultry, small ruminants and pigs are left straying. As for cattle, they are raised in herds by the owners.

The productivity and profitability of the major crops and processing activities listed above are affected by constraints confronting the farms in the cotton zone of Northern Benin. The major constraints to agricultural production are: decline in soil fertility, attacks of stocks of agricultural products, proliferation of *Striga spp* in the fields, low mechanization of cropping operations and processing methods as well as the lack of labor for cropping operations (INRAB, 2018). The severity of these constraints depends on the gender of the producers. The priority constraints for women producers are decline in soil fertility, low mechanization of cropping operations and processing methods, lack of clean water for processing as well as the pest attacks of the agricultural products. On the other hand, male producers are mainly confronted with the proliferation of Striga spp in the fields, the inexistence of storage facilities for plant products, and the non-availability of processing equipment (mill, press).

Types of farms and farm households

There is a large variation among farms and farm households according to household composition, land holding, wealth, farm equipment, and their risk-bearing capacities. Using a functional typology approach, Adegbola et al. (2017) identified four major farms and farm' households' types in each of the two sub agro-ecological zones of the cotton zone of Northern Benin. Figure 2 presents the importance of each type in the two sub agro-ecological zones. Type 1 of farm households is the most important in the agro-ecological sub-zone 1 (33.3%). In contrast in the agro-ecological sub-zone 2, most farm households are from the type 4 (44%).

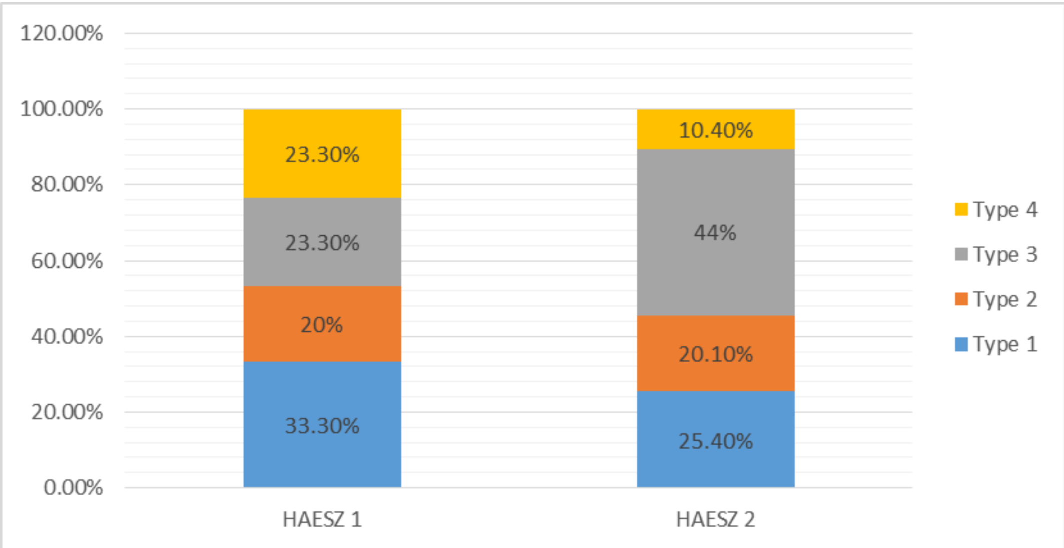


Figure 2: Percentage of types of agricultural holdings by homogeneous agro-ecological sub-zones

Source: Adegbola et al., 2017

The main characteristics of each type of farm households is summarized as follows:

Agro-ecological sub-zone 1 (HAESZ1)

Type 1: Moderately vulnerable holdings

Here vulnerability is characterized by a food deficit with the absence of livestock. On average, the balance in pulses is 627.33 kg, which is lower than those of types 3 and 4. The moderately vulnerable holdings have CFA franc 240,000 as credit amount and possess 21 herds of cattle. Off-farm activities have little contribution in their total income. They practice neither paddock breeding nor straying and produce 8.62 kg of cotton per man-day. Their ratio of number of consumers to the number of workers exceeds unity, which suggests that all consumers do not participate in farm activities. They grow 1.45 hectare of legumes and 1.5 hectare of plantation.

Type 2: Extremely vulnerable holdings
Extremely vulnerable holdings have an average of nine head of cattle. Off-farm activities contribute more to their total income compared to other types of holdings. Only the paddock breeding is practiced by 10% of them. These holdings produce on average 6.79 kg of cotton per man-day, which is lower than the productivities of Agricultural Households of types 1 and 3. Their ratio of the number of consumers to the number of workers is 1.32. They grow one hectare of legumes and 1.04 hectare of plantation.

Type 3: Highly vulnerable holdings
On average, the legume balance of highly vulnerable holdings is 1,016.43 kg, which is lower than that of type 4. Contribution of off-farm activities in their total income is almost zero. Unlike Agricultural Households of type 2, they do not breed in paddock. They produce 10.43 kg of cotton per man-day, which is higher than the productivities of AH of type 1, 2 and 4. They cultivate 1.4 ha of legumes and 1.37 hectare of plantation. Finally, their ratio of number of consumers to the number of workers is 1.61.

Type 4: Low-risk holdings
The balance in pulses of Low-risk holdings is on average 7,177.8 kg, which is higher than in types 1, 2 and 3. They have 18 head of cattle and the contribution of off-farm activities in their total income is 1.57. Like Agricultural Households of type 2, they practice weakly paddock breeding. They produce an average of 7.24 kg of cotton per man-day. Their ratio of the number of consumers to the number of workers is 1.35. Finally, they grow a large hectare of legumes (9.75) compared to other types of holdings.

Agro-ecological sub-zone 2 (HAESZ2)

Type 1: Traditional holdings
Traditional holdings have on average a lower pulses balance (214.73 kg) than those of types 2, 3 and 4. They are located about one km from their field and practice both paddock breeding (11.9%) and straying (9%). Contributions of off-farm activities and livestock to their total income are respectively 2.87 and 1.8 out of 10. They grow 7.34 hectares of cereals, 0.7 hectare of legumes and 1.49 hectare of plantation. They yield 1,775.71 kg of peanut per hectare, 2,388.46 kg of rice per hectare. Furthermore, they are technically more efficient in yam production (20,375 kg per hectare) than those of types 2, 3 and 4.

Type 2: Holdings with little diversification in off-farm activities
They practice both paddock breeding (4.5%) and straying (18.7%). Their pulses balance (408.18 kg) is lower than that of types 3 and 4. Off-farm activities contribute more to their total income compared to type 1, 3 and 4. Livestock production in their total income is low (1.81 out of 10). They grow 16.61 hectares of cereals, which is greater than the case of types 1, 3 and 4. They grow 0.61 hectare of pulses and 0.81 hectare of plantation. As technical performance, they yield 3,035.41 kg of rice per hectare, 8,472.82 kg of yam per hectare and 2,486.67 kg of peanut per hectare.

Type 3: Subsistence holdings

The food or subsistence farms have on average a balance in pulses of 548.95 kg, which is greater than that of types 1 and 2. The distance from the house to the field is about 2.5 kilometers from their field. Unlike types 1 and 2, they only practice straying (41%). Contributions of off-farm activities and livestock to their total income are respectively 1.71 and 1.9 out of 10. They grow 6.23 hectare of cereals, 1.06 hectare of legumes and 0.81 hectare of plantation and use 912.5 kg of organic fertilizer. They yield 1,564 kg of peanut per hectare, 2,108.89 kg of rice per hectare and 7,778.78 kg of yam per hectare.

Type 4: Extensive holdings

Extensive holdings practice hardly paddock breeding (0.7%) but weekly (7.5%) the straying. Their pulses balance (11,773.07 kg) is higher than those of types 1, 2 and 3. Contributions from off-farm activities and livestock to total income are respectively 2.14 and 1.69 out of 10. They grow 10.91 hectare of cereals and 2.53 hectare of legumes. Their planting area (6.4 hectare) is higher than those of types 1, 2 and 3. Finally, they yield 2,500.18 kg of peanut per hectare.

Degree of mechanization (tools) by type of farm-households

Agricultural mechanization is the application of mechanical technology and increased power to agriculture (FAO, 2008, p. 1; Ströh de Martínez et al., 2016). In terms of scope, mechanization refers to tools and machines for enhancing the value of land, production and post-harvest techniques such as processing, storage and transport (Side and Havard, 2015). This includes the use of tractors of various types as well as animal-powered and human-powered implements and tools, and internal combustion engines, electric motors, solar power and other methods of energy conversion. Mechanization also includes irrigation systems, food processing and related technologies and equipment (Ströh de Martínez et al., 2016; Side and Havard, 2015). These tools can reduce food loss and offer new opportunities for income gains and diversification.

Farms in the northern cotton zone of Benin are beginning to experience some mechanization favored by cotton cultivation. Animal draught power is used in all farms to plow (using a plow), to transport and to spray (Table 1). Only one farm used tractors in addition to animal draught power. No family farm uses cultivators.

Table 1: Average number of each type of farm equipment (Unit) owned per type of farm

Types of EFP	Types of equipment											
	Plow		Draught and transportation animals		Tractors		Sprayer		Cart		Ridger	
	Average	R/N	Average	R/N	Average	R/N	Average	R/N	Average	R/N	Average	R/N
Type 1	1.57 (1.08)	18/34	4.33 (4.20)	18/34	2.00 (0.00)	1/34	1.94 (1.34)	16/34		0/34		0/34
Type 2	2.25 (1.04)	10/10	4.90 (2.81)	10/10		0/10	2.00 (1.22)	5/10	1.00 (0.00)	1/10		1/10
Type 3	1.35 (0.49)	23/26	3.3 (91.47)	23/26		0/26	2.75 (2.02)	16/26		0/26	1.00 (0.00)	1/26
Type 4	2.33 (1.53)	4/4	4.75 (3.77)	4/4		0/4	4,67 (2,89)	3/4		0/4		0/4

() Standard deviation; R/N= Number of respondents /total number, Sample size AEZ2= 79, Number of respondents = 74

It can be noted that none of the surveyed types of farms has a cultivator, a harrow or a seeder.

Table 2 explores the degree of animal draught power and related materials utilization.

Table 2: Average number of available equipment per number of pairs of draught and animal for transportation per type of farm

Types of EFP	Average number of pairs of draught and transportation animals		Number of equipment per pair of draught and transportation animals					
			Cart		Plow		Ridger	
	Average	R/N	Average	R/N	Average	R/N	Average	R/N
Type 1	2.17 (2.1)	18/34	.	0/34	0.93 (0.36)	16/34	.	0/34
Type 2	2.45 (1.4)	10/10	0.25	1/10	1.36 (1.89)	8/10	.	0/10
Type 3	1.7 (0.73)	23/26	.	0/26	0.85 (0.21)	22/26	.	0/26
Type 4	2.38 (1.89)	4/4	.	0/4	0.87 (0.12)	3/4	.	0/4

() Standard deviation; R/N= Number of respondents /total number, Sample size AEZ2= 79, Number of respondents = 74

The performances of this equipment are low compared to the technical potential. Thus, we note that the tools used are not much diversified: 1.36 to 0.85 plow/yoke of oxen. For animal draught cultivation, producers often content themselves with one plow. Only one producer has carts, while none of them has a ridger, a cultivator, a harrow or a seeder. While in Benin conditions, we can envisage three or four tools per yoke of oxen. This statement tallies with the results of (FAO, 2005; P. 33.).

Analysis of the low use of machinery on the farms

Table 3 shows the most tedious manual agricultural operations given by men and women producers during a survey conducted by Agbangba et al. (2018).

Table 3: Results of the Rank cluster of the ranking by degree of hardness of cropping operations

Crops	Soil preparation	Plowing	Weeding	Seeding	Spraying	Harvesting	π
Maize	6	1	2	3	4	5	0.79
Cassava	1	2	3	4	5	-	0.74
Cowpea	-	1	2	3	-	4	0.69
Groundnut	-	1	2	3	-	4	0.85
Soya	1	2	3	4	-	5	0.74
Rice	-	1	2	3	-	4	0.63

This table reveals that plowing, soil preparation, weeding and seeding are the most difficult operations cited for all crops. The less cited hard operations are spraying and phytosanitary treatment of plant (Table 3). The conclusion is that these agricultural operations must be mechanized to make life easier for producers.

Use of improved agricultural technologies on the farms

Technology is usually defined by economists as a stock of available techniques or a state of knowledge concerning the relationship between inputs and outputs (Colman and Young, 1989). Different technologies are used by the types of agricultural holdings in both homogeneous agro-ecological sub-zones.

Table 4 presents the status of utilization of new agricultural technologies. Most of the family farms do not use the improved varieties of major crops. Certified maize seeds are used by type 3 on about only 36% of the cultivated area. On the other hand, all the four types of farms use inorganic fertilizers and pesticides. However, application of organic fertilizers to maintain and restore the soils is not much practiced in these farms.

Table 4: Quantities and average acreages of improved technologies and per type of farm in AEZ 2

Types of technologies	Technology	Types of EFP											
		Type 01			Type 02			Type 03			Type 04		
		Acreage of the technology (ha)	Average quantity of the technology (kg, L)	Cultivated area (ha)	Acreage of the technology (ha)	Average quantity of the technology (kg, L)	Cultivated area (ha)	Acreage of the technology (ha)	Average quantity of the technology (kg, L)	Cultivated area (ha)	Acreage of the technology (ha)	Average quantity of the technology (kg, L)	Cultivated area (ha)
Improved varieties	Certified maize seed EDVT			1.96 (2.64)			3.54 (4.94)	0.75		2.10 (2.51)			4.03 (5.67)
Soil fertility management	Urea fertilizer	1.48 (1.23)	75.00 (35.36)	1.96 (2.64)	0.68 (0.25)	206.25 (210.76)	3.54 (4.94)	1.38 (1.31)	123.33 (191.67)	2.10 (2.51)	2.40 (1.18)	100.00 (0.00)	4.03 (5.67)
	NPK fertilizer		102.50 (58.27)			200.00 (235.85)			163.75 (345.22)			150.00 (0.00)	
	Crop residues							1.34 (1.28)					
Phytosanitary treatments	Herbicide	1.46 (1.22)	1.26 (1.16)	1.96 (2.64)	3.17 (3.05)	1.95 (2.24)	3.54 (4.94)	1.58 (1.40)	2.40 (3.49)	2.10 (2.51)	2.69 (1.08)	2.48 (1.95)	4.03 (5.67)
	Insecticide	1.60 (1.30)	0.48 (0.24)		0.69 (0.41)	2.12 (1.91)		1.86 (1.22)	0.82 (0.50)		3.19 (0.78)	0.58 (0.11)	

Sample size AEZ2= 79, Number of respondents = 60

Sampling

The most representative agricultural holding of each type was selected for the modeling purpose on the basis of the value of posteriori probability. In addition, the selected agricultural holdings were those showing data in crop production, animal production and processing, and with few missing data. This procedure permitted selection of representative agricultural holdings (Table 5). Furthermore, case studies were used rather than synthetic composite agricultural holdings because of the dangers inherent in averaging resource availabilities and other structural parameters.

Table 5: Representative agricultural holdings selected for the modelling

Types of EFP	**AEZ 2**	
	HAESZ1	***HAESZ2***
Type 1	196 -Prod Ani -Prod Veg	211 -Prod Ani -Prod Veg
Type 2	202 -Prod Ani -Prod Veg	160 -Prod Ani -Prod Veg - Transfor
Type 3	204 -Prod Ani -Prod Veg	159 -Prod Veg -Prod Ani
Type 4	203 -Prod Ani -Prod Veg -Transfor	178 -Prod Veg

Source: Authors' construction/computation.

The agricultural holdings in this technical report are two of the height selected. There are agricultural holdings numbered 196 and 159, of type 1 and type 3, respectively.

Research Methods

Theoretical framework

The adoption of new agricultural technologies alleviates constraints related to production technologies and increases the profit generated by agricultural production activities and mainly the revenue of the producer and of his/her household. An increase in the revenue of the farmer leads to changes in the demand of food and non-food products. Interactions between production and consumption are extremely sensitive to the level of integration of the households into the markets of products and of production factors. In fact, if the markets for products and of production factors exists and works correctly; production decisions are independent of the consumption ones. But in reality, the producer operates in an environment where the market exists and functions well for some products and production factors, while they do not exist for others. For example, there might be a labor market for a product but the excessive transaction cost the producer is facing to sell or to send a food product may discourage him/her to participate in the commercial transactions. He/she may then prefer to secure self-sufficiency of his/her household through his/her own production (Taylor and Adelman, 2002). The market failure is not specific to a product or to a production factor. It is rather specific to agricultural households. In general, markets exist, but their failure is linked to the types of agricultural households for which the concerned product or production factor is not exchangeable (Janvry *et al*., 1991). In the context of market failure, production and consumption decisions are taken simultaneously. In this case, the effect of the whole political intervention should be traced through simultaneous changes both in the production and consumption of the agricultural household. That is why when a new agricultural technology is introduced, the production behavior will be immediately and directly affected. The increase in the resulting profits will induce changes in good consumption and time devoted to leisure activities. Therefore, the global effect of a new agricultural technology adoption can be assessed only by the application of a model that integrates simultaneously the decision process of the agricultural household regarding production and consumption (Barnum and Squire, 1979). The agricultural household model is more appropriate in analyzing the decisions to adoption or rejection of the high yielding maize variety cropping and the machinery. It anticipates all changes that its adoption may entail on all components of the farm and also, it gives sufficient information on the factors limiting the adoption. These factors may be linked to land restrictions, labor and the budget available that limit the adoption. By so doing while giving an overview of the financial, economic and social impacts of the high-yielding maize variety cropping and the machinery, the analysis based on the model of agricultural household informs about the net profit of its adoption compared to the other agricultural and non-agricultural activities presented to farmers. It also integrates requirements relating to the production levels of certain crops necessary for food and non-food needs of the family. (Adégbola, 2010).

The construction of the household model is underlined by the “theory of farming economy” of Chayanov relating to resource allocation and to the differentiation between farm households. It is criticized by Harrison and Patraik (Chayanov, 1966; Harrison (1975; Patraik, 1979). In fact, Chayanov showed that the allocation of resources at the farmer’s level is done based on their rationality and therefore introduced a determining element in the traditional conception of farming economy. It then postulates that it is the ratio c/w (consumer per active person) that determines the cultivated area per active person at the level of the household and therefore the size of the farm. In other respects, Chayanov shows that in situation of land constraint, households having the high c/w ratio l tend to intensify work on their farms. On the contrary, Harrison (1975) argues that such intensification supposes a shift from the extensive cropping system to the intensive cropping system. This shift to an intensive system requires means that farmers do not always have. In other respects, for Chayanov, the distinction between the households is a demographic phenomenon that takes place through life cycle. Patnaik (1979) argues on the contrary that is a phenomenon of social differentiation and shows that it is often rich farmers who have big households. Harrison (1975) found out that small farmers do not have the necessary means to have big households and that they are often obliged to go and work for big farmers to get some money.

The theory of Chayanov was then developed in a neo-classic frame by Tanaka (1951, cited by Nakajima, 1986) and Nakajima (1986). Nakajima names it subjective equilibrium theory of the farm household. He developed this theory to facilitate the analyses of commercial as well as subsistence farm holdings. The subjective equilibrium theory of the farm household stipulates that the farm household makes its consumption and production choice in order to maximize the unit of consumption submitted to a set of constraints, including those relating to production technologies and constraints on complete benefits. It derives from these theories that analyses should be conducted based on the major types of farm holdings. Each type of farm holding faces opportunities and constraints that influence its decisions and justify its behaviors regarding agricultural technologies. In this study, a theoretical model of the farm household behavior was developed based on the models of Chayanov (1966) and the criticisms of Harrison (1975) and Patraik, (1979) then the model of Nakauma (1986). The model of farm household applied in this study integrates seasonality in all the activities, resources and food consumptions. It also takes into account the nutrition levels of the members of the farm household.

Prospective mechanization tools in the cotton northern area of Benin

A study by Agbangba et al. (2018) identified the mechanization tools wanted by farmers to lighten the hard production operations. These mechanization tools are summarized in table 6.

Table 6: Mechanization tools by crops and difficult cropping operations

Type of traction	Material	Operations				
		Plowing	Leveling	Weeding	Seeding	Soil preparation
Power tiller	Turn plow for power tiller	Maize				
	Rotating cultivator for power tiller		Maize			
Tractor (Type of attachment: three points)	Disk plow	Maize, Rice				
	Offset sprayer		Maize			
	Super eco seeder: Cereal line seeder:				Maize, Rice	
	Disk plow	Soya; Cassava				
	Motorized weeder			Soya		
	Motorized sprayer			Maize		
	Cassava planting machine				Cassava	
	Grubbing					Cassava
Long handle hoe	Herbicide			Maize		
Manual sprayer				Maize		

Prospective high yielding maize varieties

New technologies are different ways of undertaking current or new activities compared with farmers' existing practice (Anderson and Hardaker, 1979; Torkamani, 2005). To address the major constraints experienced by producers, the following technologies were developed by research.

A multitude of improved maize varieties are found in Benin. They are developed at the International Institute of Tropical Agriculture (IITA) in Ibadan and tested in different agro-ecological zones of Benin for their adaptation. Based on the agronomical and socioeconomic characteristics, the extra-early and early varieties and the short-cycle varieties are the two groups deemed good and appreciated by users. The varieties 2008 SYN EE-Y DT STR and 2008 SYN EE-W DT STR (too early) have yellow grains and appreciated for their high content in provitamin. However, among these two groups of varieties, 2008 SYN EE-Y DT STR is very sensitive to Striga and the varieties Ilu Jama (TZEE SR W); 2008 EV DT-STR Y; Mougnangui or EV DT 97 STR W; BEMA94 B15 Miss Ina (AK 94 DMR ESR Y) are moderately resistant to this bad weed. These varieties are less appreciated by producers.

Specification of the mathematical model

The choice of model was based on the theoretical framework developed in the sub- section 2.2.1. The household farm investigated involve the production of various crops jointly with raising animal; and undertaking processing and off-farm activities. Thus, the problem investigated necessarily involved whole-farm analysis of a complex mixed farming system in the cotton Northern zone. In whole-farm planning, mathematical programming techniques have provided a fruitful line of applications. Of this linear programming (LP) is one of the most widely used analytical methods. However, it excludes the possibility of accounting directly for a decision maker's nonneutral attitude to risk. Farmers in developing countries operate in a high uncertain environment and most of them are averse to risk. This drawback can be overcome to some degree by various extensions of the technique such as, the linear alternative minimization of total absolute deviation approach (MOTAD) (Hazell, 1971). However, the MOTAD does not necessarily meet the second-degree stochastic dominance (SSD) criteria. Target MOTAD developed by Tauer (1983) is a method that generates a subset of feasible solutions that satisfy SSD criteria by using linear programming algorithms (Tauer, 1983 ; Zimet and Spreen, 1986 ; Berbel, 1989 ; Novak, 1990 ; Adegbola, 1997). For that, the Target MOTAD model is said to be superior to other programming models under risk (Tauer, 1983; Monishola and Oladipupo, 2012).

Target MOTAD is defined by Tauer (1983) as a two-attribute risk-return model. Return is measured as the sum of the expected returns of activities multiplied by their individual activity level. Risk is measured as the expected sum of the negative deviations of the solution results from a target-return level. The principal purpose of risk-return analysis lies in ranking alternative farm plans on the basis of risk, and examining trade-offs between risk and mean income. Risk is varied parametrically, so that, a risk-return frontier is traced out. A target-MOTAD formulation can be useful because decision makers often wish to maximize expected returns but are concerned about net returns falling below a critical target level (Watts et al, 1984; Zia, 1992; Torkamani, 2005). Target MOTAD maximizes mean income subject to a limit on the total negative deviation measured from a fixed target rather than from the mean (Torkamani, 2005). The Target MOTAD may thus provide a suitable framework for assessment of the potential adoption of high yielding maize varieties and use of machinery by type 1 and type 3 household-farms in the context of farm circumstances in cotton northern zone of Benin. Such models can simulate farmers' behavior in terms of his or her goals, attitudes, preferences and circumstances, and provide useful information regarding possible impacts of prospective technology on farmers' welfare and also on policy instruments such as employment, prices, and the distribution of income. The theoretical Target-MOTAD model was specified as (Tauer, 1983; Zia, 1992):

$$\boldsymbol{Maximize\ E(z) = \sum_{j=1}^{n} c_j x_j} \qquad (1)$$

***Under constraint of*:**

$$\boldsymbol{\sum_{j=1}^{n} a_{kj} \leq b_k} \qquad \boldsymbol{k = 1, \dots, n} \qquad (2)$$

$$\boldsymbol{T - \sum_{j=1}^{n} c_{rj} x_j - y_r \leq 0} \qquad \boldsymbol{r = 1, \dots, s} \qquad (3)$$

$$\boldsymbol{\sum_{r=1}^{s} p_r y_r \leq \lambda} \qquad \boldsymbol{\lambda = M \rightarrow 0} \qquad (4)$$

For any x_j and $y_r \geq 0$, with: $E(z)$: the sum of revenues expected from the activities; c_j: revenue expected from the activity *j* ; x_j : level of activity *j* ; a_{kj} : technical coefficient of activity *j* for the constraint *k* ; b_k : Level of constraint *k* ; T : Target level of the revenue; c_{rj} : Revenue of the activity *j* for the state of nature *r* ; y_r : deviation below the target level of revenue for the state of nature *r*; p_r : occurrence probability of the state of nature *r* ; $\boldsymbol{\lambda}$: Level of risk; n : number of equations of constraints; s : Number of the states of nature.

Equation (1) maximizes the expected revenue from the different activities while equation (2) translates the different technical and economic constraints. Equation (3) measures the revenue of each production plan for the state of nature *r.* If this revenue is lower than the target level T, the difference is transferred to equation (4) via the variable y_r. Equation (4) corresponds to the sum of the negative deviations multiplied by their respective occurrence probability p_r.

Estimation of the Target MOTAD

- Objective function

The objective function (Z) represents the objective that the farm is targeting. In fact, any farm is supposed to adopt a rational behavior and seeks to maximize its profit under constraint of its available resources. This function is represented by the sum of the various revenues derived from the activities of the farm and which support the production costs, the loans and purchase fees of food products for the household. The Target MOTAD has a structure similar to that of the deterministic model, but integrates new parameters (the states of nature: their parameters and the occurrence probabilities; the target revenue). The new parameters represent the weighted average of the parameters of each state of nature, by their respective occurrence probabilities. In our case, we opted for an objective function that maximizes the total raw margin resulting from the different activities carried out by the farm.

$$Z = \sum_{p\,j\,ex} \boldsymbol{REVENU(j,p,ex)} - \sum_{p\,j\,ex} \boldsymbol{COUT(j,p,ex)} + \sum_{p\,c\,ex} \boldsymbol{EMPRUNT(p,c,ex)} - \sum_{pd\,ex} \boldsymbol{CREMB(pd,ex)} + \sum_{ex} \boldsymbol{cash(ex)}$$

$$+ \sum_{p\,ex} \boldsymbol{autrec(p,ex)} - \sum_{ex} \boldsymbol{autdep(p,ex)} - \sum_{p\,ex} \boldsymbol{CACHAL(p,ex)} \qquad (5)$$

$\mathrm{REVENU(j,p,ex)}$: *Revenue derived from activties **j** for each period **p** and for the farm **ex***

$\mathrm{COUT(j,p,ex)}$: Cost derived from activities ***j*** for each period ***p*** and for the farm ***ex***

$\mathrm{EMPRUNT(p,c,ex)}$: The type of loan ***c*** obtained during the period ***p*** of the farm ***ex***

$\mathrm{CREMB(pd,ex)}$: The amount of reimbursement of the loan during the period ***p***

$\mathrm{CACHAL(p,ex)}$: The purchase price of food consumed for the period ***p*** of the farm ***ex***

$\mathrm{cash(ex)}$: Cash available at the beginning of the season for the farm ***ex***

$\mathrm{autrec(p,ex)}$: Other revenue obtained during the period ***p*** and by the farm ***ex***

$\mathrm{autdep(p,ex)}$: Other expenditures made during the period ***p*** by the farm ***ex***

- Definition of the constraints

- **Land constraint**

Land use constraint indicates that the total cultivated area per crop system ***sc*** and per equipment ***eq*** used in the farm ***ex*** defined SUP (sc,eq,ex) should not exceed the total acreage available represented by the ***land*** (***land*** *parameter*). This constraint is formulated as follows:

$$\sum_{sc\,eq} \boldsymbol{SUP(sc,eq,ex)} \leq \boldsymbol{terre(ex)} \qquad (7)$$

The total available acreage for the farm represents all the exploitable plots that are under the farm control no matter the access mode and is presented in the table below:

Table 7: *land (ex)* total available acreage in Hectare (Ha)

Type of farm	Total available acreage in Ha
ex11	24.12
ex13	19.87
ex21	19.59
ex23	17.67

Source: BSREA, 2017

- **Labor constraint**

Labor is an important factor in agricultural production. In fact, labor requirement in each cropping system per period p per equipment (*parameter* besmo*(p,sc,eq,ex)* on the farm, should be lower than the labor availability within the farm (*parameter modispo(p,ex)*). Family labor insufficiency in the production process, leads to the recruitment of paid labor. Labor constraint is formulated through the following equation:

$$\boldsymbol{BEMOV(p,ex) \leq BEMOSV(p,ex) + modispo(p,ex)} \qquad (\mathbf{8})$$

With,

$$\sum_{sc\ eq} \boldsymbol{besmo(p,sc,eq,ex) * SUP(sc,eq,ex) = BEMOV(p,ex)} \qquad (\mathbf{9})$$

$\boldsymbol{BEMOV(p,ex)}$**:** Labor requirement for plant production per period for the farm.

$\boldsymbol{BEMOSV(p,ex)}$**:** Paid labor requirement for plant production per period for the farm.

Table 8: *modispo(p,ex):* Labor availability in Man-Day

Period	Type of farm			
	ex11	ex13	ex21	ex23
p1	60.14	145.03	58.70	134.20
p2	72.90	135.00	219.90	74.59
p3	70.06	115.73	86.95	133.39
p4	19.63	42.60	49.50	67.61

Source: BSREA, 2017

- **Capital constraint**

Money availability is one of the factors that determine the choice of production activities (Ouédraogo, 2005). For its operation, the farm often needs funds to support the costs of the different activities. In the case of this study, the different costs are supported by the revenues gained from the different activities of the household and the loans.
The capital constraint is formulated through the following equation:

$$\sum_{p\,j} \boldsymbol{COUT(j,p,ex)} + \sum_{p} [\boldsymbol{CACHAL(p,ex)} + \boldsymbol{autdep(p,ex)} + \boldsymbol{CREMB(p,ex)}]$$
$$\leq \sum_{p\,j} \boldsymbol{REVENU(j,p,ex)} + \sum_{p} \boldsymbol{autrec(p,ex)} + \sum_{p\,c} \boldsymbol{EMPRUNT(p,c,ex)} + \boldsymbol{cash(ex)} \qquad (\mathbf{10})$$

$\mathrm{REVENU(j,p,ex)}$: $\mathit{Revenue\ derived\ from\ activities}\ \boldsymbol{j}\ \mathit{for\ each\ period}\ \boldsymbol{p}\ \mathit{and\ for\ the\ farm}\ \boldsymbol{ex}$

$\mathrm{COUT(j,p,ex)}$: Cost derived from the activities ***j*** for each period ***p*** and for the farm ***ex***

$\mathrm{EMPRUNT(p,c,ex)}$: The type of loan ***c*** obtained during the period ***p*** of the farm ***ex***

$\mathrm{CREMB(pd,ex)}$: The amount of reimbursement of the loan at the period ***p***

$\mathrm{CACHAL(p,ex)}$: The purchase price cost of food consumed for the period ***p*** of the farm ***ex***

$\mathrm{cash(ex)}$: Cash available in the beginning of the season by the farm ***ex***

$\mathrm{autrec(p,ex)}$: Other revenue obtained during the period ***p*** and by the farm ***ex***

$\mathrm{autdep(p,ex)}$: Other expenditures made during the period ***p*** by the farm ***ex***

- **Risk consideration**

Farmers' aversion to risk is an important issue: It explains why they don't intensify, why they diversify, etc. There are different ways to introduce the risk in the PL. In this study, we have used the target MOTAD proposed by Tauer (1983). The risk is attributed to each state of nature and corresponds to negative deviations of the revenue compared to the target revenue (Tauer, 1983). The function objective is not modified; its coefficients are the mean of different states of nature observed. The different states of nature are introduced in specific constraints. The target revenue is lower than the value of the function objective without any risk. In its modeling, the risk is represented by the *variable* ***RISQUE***; the target revenue is represented by the *parameter* ***TARGET*** and the deviations are represented by the *variable* ***DEV***. The following two equations show the risk considered in the model:

$$\begin{aligned}&\sum_{p\,d}\big(\boldsymbol{PRODVV(p,d,ex)*ecapuvv(p,ex,en,d)}\big)-\sum_{p\,d}\big(\boldsymbol{QALACH(p,d,ex)*ecapuav(p,ex,en,d)}\big)\\&+\sum_{p\,sa}\big(\boldsymbol{PRODAV(p,sa,ex)*ecapuva(p,ex,en,sa)}\big)-\sum_{p\,sa}\big(\boldsymbol{ACHANIM(p,sa,ex)*ecapuaa(p,ex,en,sa)}\big)\\&+\sum_{p\,d}\big(\boldsymbol{PRODTV(p,d,ex)*ecapuvt(p,ex,en,d)}\big)+\boldsymbol{TARGET(en,ex)}+\boldsymbol{DEV(en,ex)}\ \geq \boldsymbol{0} \qquad (\mathbf{15})\end{aligned}$$

$$\sum_{en}\big(\boldsymbol{proba(en)*DEV(en,ex)}\big)\ \leq \boldsymbol{RISQUE(ex)} \qquad (\mathbf{16})$$

Where the new variables are:

$\boldsymbol{PRODVV(p,d,ex)}$**:** Plant production sold
$\boldsymbol{PRODAV(p,sa,ex)}$**:** Animal production sold
$\boldsymbol{PRODTV(p,d,ex)}$**:** Production from processing sold
$\boldsymbol{QALACH(p,d,ex)}$**:** Quantity of consumed food purchased
$\boldsymbol{ACHANIM(p,sa,ex)}$: Purchase of animals
$\boldsymbol{ecapuvv(p,ex,en,d)}$**:** Standard deviation of unit selling price of plant products
$\boldsymbol{ecapuav(p,ex,en,d)}$**:** Standard deviation of unit purchase price of consumed products
$\boldsymbol{ecapuva(p,ex,en,sa)}$**:** Standard deviation of unit selling price of animals
$\boldsymbol{ecapuaa(p,ex,en,sa)}$**:** Standard deviation of unit purchase price of animals
$\boldsymbol{ecapuvt(p,ex,en,d)}$**:** Standard deviation of unit selling price of products from processing
$\boldsymbol{proba(en)}$ **:** Occurrence probability of each state of nature

- **Choice of the states of nature**

Due to the rainfed nature of agriculture, three states of nature related to rainfall were the object of BSREA. They can be appreciated by farmers through agricultural yields and the quantities of rains fallen during the campaign. These are the following: Bad – Normal – Good. The state of nature 'bad' characterizes a year where climate risks (namely drought and low rainfall) are noticeable with negative impacts on production (INRAB, 2016).

To identify the different states of natures, the method of subjective probabilities was used. (Houedjissin, 2012; Mikemina *et al.*, 2014). We used the probabilities calculated by Olou in

2017, corresponding to the same zone of work. It is a matter to ask farmers the frequencies of occurrence of the states of nature, and to give an idea about agricultural yields during the periods. Data from the perception are to be taken with caution; they are therefore compared with the evolutions of yields and the rainfall in the region. Information mentioned previously allowed us to calculate the occurrence probability of the states of nature *good, normal* and *bad* which are respectively 42.8%, 42.8% and 14.4% (Olou, 2017).

Table 9: Occurrence probability and reference year of the states of nature

States of nature	Occurrence probability	Reference year
Good	42.80%	2012
Normal	42.80%	2013
Bad	14.40%	2014

Source: BSREA, 2017

- Choice of the target revenue

To fix the target revenue in the model, we opted for the poverty threshold. This indicator corresponds to the minimum expenditures required by an individual or a household to meet his/her/its basic needs, food or non-food. The global poverty threshold registered some increase from 2011 to 2015; it is on average FCFA 140,808 /Equivalent-adult/year (EMICoV-Suivi, 2015).

The formulation of the equations of the programming model will be carried out with the GAMS software. The use of this software is justified by the fact that it makes it possible to formulate models in the form of mathematical equations by relating the various variables or coefficients (Deybe, 1995). With this software, initially an optimization will be made on the current operation of farms. In a second step, the model will be calibrated by comparing the actual situation with the results of the model. Equations of farm behavior will be introduced in the model to bring the results of the model closer to reality. Finally, in a third phase, simulations will be made to measure and / or anticipate the impacts of promising technologies on agricultural households.

Data

Data for representative farming systems in the northern cotton zone of Benin for this research originated primarily from an existing data base of the Benin National Agricultural Research Institute (INRAB). These data were collected using a cross-route survey conducted during 12 months, from July 2014 to June 2015 in the Alibori and Borgou departements in North-East Benin (Carte d'Identité Rurale (CIR)). A complementary survey was conducted in 2017 in the Northern cotton zone to collect the missing data. Data were collected from the selected representative agricultural holdings of each type and in each homogeneous sub-zone. Secondary sources such as other INRAB programs and review of literature were used to complement and refine the collected data. Data collected included crop yields, quantities of various inputs (such as labor availability and use for various farm activities, machinery use, inputs and outputs producer prices, cash availability, etc.), livestock system, and consumption. These data are used to generate coefficients for the target models constructed for the two types of farms and farm households selected for this research. Other details on data sources and the budgets used to obtain many of the coefficients in the model are available from the first author.

Data regarding detailed input–output coefficients and prices of inputs and outputs for the high-yielding maize variety were obtained from a previous work conducted in 2016 in the framework of PARI Project. These data were collected from the on-farm trials or from farmers who had already adopted such varieties. Coefficients for the machinery use, were constructed from data obtained from secondary sources.

Results and Discussion

This section presents in detail the results in respect of the different models used in the study. The Target model was used to examine three scenarios: base case, maize high yielding varieties adoption and the use of mechanization tools.

Mathematical model validation

The results of the Target base models compared with known data from Adegbola et al. (2017) are presented in Table 10. They are useful for validating both models by comparing the cropping plan predicted by each to the actual cropping plans observed on farmers' fields. In addition, they are used in determining the impacts of the high-yielding maize variety adoption and the use of machinery on the farming practices in terms of cropping and livestock activities, total crop land (hence, land rented); total herd size and cropping intensity. These changes occur mainly in farm income, consumption and nutritional behaviors, and marketed surplus.

Table 10: Crop allocation and income statistics for base technologies

Variables	**Farm type**					
	Type1			Type3		
	Observed values	Model base	Variation (%)	Observed values	Model base	Variation (%)
Crop enterprises (ha)						
Cotton_atte	8.913	8.913	0	5.33	5.177	-2.87
Maize_atte	7.424	7.424	0	11.35	11.503	1.35
Groundnut	0	0		0.99	0.99	0
Sorghum	6.099	6.099	0	0	0	
Millet_atte	0.772	0.77	-0.26	0	0	
Yam_atte	0.913	0.915	0.22	0	0	
Total cultivated land	24.121	24.121	0	17.67	17.67	0
Income over consumption	7733545	7176100	7.21	2287450	2534800	10.81
Marginal value product of resources						
Land (FCFA/ha)	870000	983210	13.01	1100000	55679	-94.94
Labour, May-July (FCFA per person day)	1863	1745	-6.32	1863	1745	-6.32

Labour August-October (FCFA per person day)	1761	1662	-5.62	1761	1662	-5.62
Labour November-January (FCFA per person day)	1588	1706	7.41	1588	1706	7.41
Labour February-April (FCFA per person day)	1588	0	-100	1588	0	-100

Adegbola et al. (2017) reports total crop areas of about 24 ha and 18 ha, respectively, for the type 1 and type 3 studied farms households. The two types of farm households cultivate cotton and maize. The types 1 and 3 allocate respectively, about nine ha and five ha to cotton. Maize is the only one cereal cultivated by the type 3 for which the highest area (11.50 ha) is devoted. The type 1 allocates about 14 ha to cereals, with about seven ha to maize (Table 10). This type of farm household does not grow any groundnut while the type 3 allocates about one ha to this crop. These figures compare to the results of the Target base models show slight differences in the cropping systems, ranging from -0.26% to -2.87%. Furthermore, results show small variations between observed shadow prices and those from base target models. We can therefore conclude that the target base models of the two types of studied farm households simulate well the situation for both household types in the cotton agricultural zone of Benin. They can be used to predict whether improved maize variety and mechanization tools would likely be adopted, and whether changes occur within the farms and farms households.

Impact of machinery use and adoption of maize high-yielding variety

Three sets of experiments were performed with the Target model. The first set consisted of comparing the Target model results with and without the maize high-yielding variety to assess the impacts of newly released varieties on income, crop mix, output and labor demand. The second set of experiments consisted of machinery use to assess its effects on income, crop mix output and labor demand. The third set of experiments was the combination of the first two to evaluate their effects on the same parameters.

The effects in terms of levels of expected income and land allocation for farms on the introduction of machineries and high yielding variety of maize on the Target models are illustrated in Table 11 and Table12 for the representative farm-households of the type 1 and type 3, respectively. The Target model results indicate that the introduction of machinery and a high-yielding maize variety would be attractive to type 1 and 3 households in the Northern cotton zone of Benin. Indeed, the incomes of the two types of farm households increase by 74.37% and 67.93% for type 1 and 3 respectively, with the use of the tractor and the adoption of the high-yielding maize variety in their farms. Results show the impact of the three experiments on income are higher for type 1 than type 3 (Table 11). The highest level of impact on income (74.37%) is obtained with the combination of an adoption of the maize high yielding variety and the use of machinery in the farm household type 1.

Increases in the farm incomes of the two types of farm households suggest that the farmer's activities should change substantially. In this way, the Target models show that the farmer in type 1 will substitute the use of draught animals for that of tractor in cotton maize and sorghum growing. Then, using the tractor in place of the draught animals, he increases the cotton area by 28.57% compared to the area of 8,913 ha of cotton in the base model. Regarding the maize growing, he adopts the high-yielding maize variety and grows it on the whole area devoted to maize. The reason could be that the maize is considered today as a cash crop in this zone. In that way, farmers use a portfolio strategy for risk management. However, results indicate that he reduces the allocation of land to maize by 37.18%. Similarly, the sorghum area is reduced by 36.07% when using the machinery. In contrast, the type 1 eliminates the allocation of land to the millet and the farmer allocates significant area to yam growing. The farmer household representative of type 1 is still using the draught animal but he increases the allocation of land to yam by about 348%. Yam is the main staple food in the northern cotton zone of Benin.

Table 11: Crop allocation and income statistics for modern varieties and mechanization tools uses in Household farm type 1

Variables	Models				Variation (%)		
	Base model (1)	Model¹ (2)	Model² (3)	Model³ (4)	(2)-(1)	(3)-(1)	(4)-(1)
Crop enterprises (ha)							
Cotton_atte	8.91	3.91	-	-	-56.10	-	-
Cotton_trac	-	-	3.08	11.46		-65.49	28.57
Total Cotton	8.91	3.91	3.08	11.46	-56.10	-65.49	28.57
Local maize_atte	7.42	-	-	-	-	-	-
Local maize_trac	-	-	10.48	-	-	41.14	-
High-yielding maize variety_atte	-	6.98	-	-	-5.98	-	-
High-yielding maize variety_trac	-	-	-	4.66	-	-	-37.18
Total Maize	7.42	6.98	10.48	4.66	-5.98	41.14	-37.18
Sorghum_atte	6.10	8.31	-	-	36.32	-	-
Sorghum_trac	-	-	6.90	3.90	-	13.12	-36.07
Total Sorghum	6.10	8.31	6.90	3.90	36.32	13.12	-36.07
Millet_atte	0.77	0	0.77	0	-100.00	0.00	-100.00
Yam_atte	0.92	4.91	2.90	4.10	436.94	216.61	347.87
Total cultivated land	24.12	24.12	24.12	24.12	0.00	0.00	0.00
Income over consumption	7176100	11384000	10344000	12513000	58.64	44.15	**74.37**
Marginal value product of resources							
Land (FCFA/ha)	983210	25971	61694	44936	-97.36	-93.73	-95.43
Labour. May-July (FCFA per person day)	1745	1745	1745	1745	0.00	0.00	0.00
Labour August-October (FCFA per person day)	1662	1662	1662	1662	0.00	0.00	0.00
Labour November-January (FCFA per person day)	1706	1706	1706	1706	0.00	0.00	0.00
Labour February-April (FCFA per person day)	0	0	0	0			

Model¹: simulation of modern maize varieties adoption; **Model²**: simulation of mechanization tools use; **Model³**: simulation of modern maize varieties adoption combined with mechanization tools use.

Table 12: Crop allocation and income statistics for modern varieties and mechanization tools uses in Household farm type 3

Variables	Models				Variation (%)		
	Base model (1)	Model[1] (2)	Model[2] (3)	Model[3] (4)	(2)-(1)	(3)-(1)	(4)-(1)
Crop enterprises (ha)							
Cotton_atte	5,18	6,06	-	-	16,98	-	-
Cotton_trac	-	-	3,53	12,41	-	-31,74	139,75
Total Cotton	5,18	6,06	3,53	12,41	16,98	-31,74	139,75
Local maize_atte	11,50	-	-	-	-	-	-
Local maize_trac	-	-	14,14	-	-	22,89	-
High-yielding maize variety_atte		10,62	-	-	-7,64	-	-
High-yielding maize variety_trac	-	-	-	5,26	-	-	-54,29
Total Maize	11,50	10,62	14,14	5,26	-7,64	22,89	-54,29
Groundnut	0,99	0,99	0	0	0	-100	-100
Total cultivated land	17,67	17,67	17,67	17,67	0	0	0
Income over consumption	2534800	3257900	3171400	4256600	28,53	25,11	**67,93**
Marginal value product of resources							
Land (FCFA/ha)	55679	32182	134260	70730	-42,20	141,13	27,03
Labour, May-July (FCFA per person day)	1745	1745	1745	1745	0	0	0
Labour August-October (FCFA per person day)	1662	1662	1662	1662	0	0	0
Labour November-January (FCFA per person day)	1706	1706	1706	1706	0	0	0
Labour February-April (FCFA per person day)	0	0	0	0			

Model[1]: simulation of modern maize varieties adoption; **Model[2]**: simulation of mechanization tools use; **Model[3]**: simulation of modern maize varieties adoption combined with mechanization tools use.

The target model results of the Type 3 farm households show a same behavior as in the type 1 with the adoption of the high-yielding maize variety and the use of the machinery on the farm. However, the increase in the area devoted to cotton with tractor is higher than for type 1 (139.75% for type 3 against 28.57% for type 1). The maize area reduction is also higher than inthe Type 1 (54.29 for type 3 against 37.18% for type 1). Just as for millet in type 1, the type 3 eliminates the allocation of land to groundnut.

Conclusions and Implications

Farm households provide up to 80% of food production in Asia and Sub-Saharan Africa. Thus they can contribute to eliminating hunger and malnutrition. Therefore, various governments of Benin show a growing interest in the promotion of agricultural holdings. Furthermore, agricultural productivity is extremely low. Therefore, increasing agricultural productivity is critical to economic growth, overall development and improved rural welfare (Gollin et al., 2002). A productivity increase in key export crops and livestock products and processing of agricultural products ensures the profitability of these products for producers, resulting in an increase in their income. Important reforms are undertaken in the agricultural sector since 2016 aiming at increasing agricultural productivity and improving food and nutrition security. One important and most used way to increase agricultural productivity is through the introduction of improved agricultural technologies and management systems. However, human capital is another important determinant and increasing this could also raise agricultural productivity thereby triggering economic growth. To increase agricultural productivity and ensure food security and nutrition, the government put emphasis on the generation of appropriate agricultural technologies, the use of machinery to lighten the hard operations in agricultural production and processing, the irrigation of farms, access to credit, etc.

This study investigates the potential adoption of high-yielding maize varieties, the use of machinery and the subsequent changes on types 1 and 3 of farms and farm households under uncertainty in the northern cotton zone. We hypothesize that farmers adopt technologies that are appropriate with respect to their own goals, preferences and resource constraints as well as to their economic and natural environments. Therefore, a whole-farm modelling approach that has the potential to provide a realistic assessment of the suitability and acceptability of technologies to farmers is applied. It compares the new technologies with farmers' existing technologies. The Target-MOTAD model was adopted in this study, which combines the concepts of stochastic dominance with respect to a function and a whole-farm programming. It can generate an efficient set of farm plans for those farmers whose absolute risk aversion functions are defined over a specified interval. The need to integrate risk in the modelling of agricultural holdings is justified by the fact that smallholders face risks related to price, yield and resource that make their income unstable from year to year. The Target-MOTAD model was used, not only because it is the most widely applied technique for these types of risk, but also because it has a linear objective function and linear constraints. The Target-MOTAD modelling approach used in the study enables us to see whether the adoption of the high-yielding maize varieties and the use of machinery are consistent or not with specified goals and objectives of farmers.

Target models' results show the use of machinery (tractor) and the adoption of the high-yielding maize variety in t types 1 and 3 of farm households in the northern cotton zone of Benin. This results in a substantial increase in of net revenue (74.37% and 67.93% for type 1 and 3, respectively). More land is allocated for cotton in the two types of farms and farm households. They adopt the high-yielding variety and abandon the local maize variety. However, the land allocated for it is reduced in the two types of farms and farm households. The type 1 and type 3 eliminate the allocation of land to millet and groundnut, respectively. In contrast, type 1 increases substantially the allocation of land to yam which is the main staple food in the northern cotton zone of Benin.

The above results show that adoption of high-yielding maize variety and machinery use have important but somewhat diverse effects on the two types of farms and farm households in the northern cotton zone of Benin. This implies a need to identify and target existing types of farms and farm households in the generation and diffusion of new technologies and the agricultural policy instruments implementation. In other words, the recommendation domains approach should be used. The model developed in the current study can be expanded to other types of farmers in other zones of Benin and can also be used to examine the effects of other technologies and policy instruments. An analysis of these policies can be the focus of future research efforts in Benin. Merely producing new technologies does not ensure their adoption, and even if new technologies are adopted their supply inducing effects can be offset or enhanced by other policy changes. Detailed whole-farms and farm households would be developed in future research to comprehensively evaluate the impact of modern technologies and the agricultural policy instruments implementation on livestock system, processing activities, off-farm activities, food security, and nutrition improvement of household members.

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Annex 1: Characteristics of improved maize varieties

Crop	Names of varieties per group of similar characteristics	Characteristics							Challenges
		Yield (Kg/ha)	**Cycle duration (days or Long/short, early)**	**Resistance or tolerance to listed diseases**	**Sensitive to the listed diseases**	**Palatability**	**Conservation**	**Access to seed**	
Maize	- Ku Gnaayi (2000 SYN EE W) ; - Ilu Jama (TZEE SR W) ; - 2008 SYN EE-Y DT STR - 2008 SYN EE-W DT STR - TZEE-Y POP STR QPM - TZEE-W POP STR QPM	3000-4000	Extra & early (80 days)	- Lodging - Leaf tripe - *Striga Hermonthica* - Streak	-	Well appreciated for pasta, akassa and porridge (good for mouth maize)	Very good coverage of the ear	Non-availability of improved seeds	
	- Ya koura goura guinm ; - Orou kpintéké ; - 2008 EV DT-STR Y - 2008 EV DT-STR QPM - Djéma bossi ; - Mougnangui or EV DT 97 STR W ; - Ouyé (DMR ESR W BENIN) ; - BEMA94 B15 (DMR ESR/QPM W) ; - Miss Ina (AK 94 DMR ESR Y);	4000-4500	Short cycle (90 days)	- Lodging - Leaf tripe - Streak - Moderate resistance to Striga	Only the variety Ya koura goura guinm is sensitive to Striga	- Very appreciated for pasta /porridge, rich in provitamin A (2008 EV DT-STR Y - 2008 EV DT-STR QPM)	Problems of seed storage, good coverage of the ear	Lack of improved seeds	The varieties 2008 EV DT-STR QPM Djéma bossi have good resistance to Striga
	- Ion-Didon; - Djéma bossi; - Saki Faba ou TZPB-SR ;	3500-4000	Intermediary and long cycle (105 – 120 days)	- Lodging - Leaf tripe	Sensitive to Striga	Well appreciated for pasta and porridge	Good coverage of the ear	Lack of improved seeds	
	- Faaba-QPM/Houinlin-mi; - TZL COMPOSITE W ; - Ya koura goura guinm				*Moderately resistant to Striga*				