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RESEARCH ARTICLE

Impact of Integrated Soil Fertility Management on Farm Income in Corn and Soybean Production in Northern Benin

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ABSTRACT

To mitigate the effects of climate variability, integrated soil fertility management strategies have been widely promoted in the West Atacora region of northern. The study assessed the impact of adopting these strategies on the agricultural income of corn and soybean producers using a logistic instrumental variable model. The results indicated that the the impact estimated Local Average Treatment Effect (LATE) revealed the average difference in net income per hectare between adopters and non-adopters, while accounting for the probability of conditional adoption based on the instrumental variables. The results show that corn producers who adopted SG Integrated Soil Fertility Management Strategy (ISFMS) have an average farm income five times higher than those who did not adopt the practice. Soybean farmers who adopted SGIFS earned an average farm income twice as high as those who did not adopt the practice. Moreover, several socio-economic factors such as the level of education, training, area planted with crops and literacy have had a positive impact on household income. Despite the negative effects of climate variability, research has shown that it is possible to improve smallholder incomes by promoting a combination of diversification and agroecological strategies in northern Benin.

1. INTRODUCTION

The need to provide food for a growing population has led to unsustainable land management practices (slash-and-burn farming, continuous cropping without rotation, intensive ploughing etc...) which, in many places, have resulted in increased land degradation and declining agricultural productivity (Dougill *et al.*, 2021). As a result, nutrient deficiencies are increasingly acute in the smallholder sector, where farmers apply sub-optimal fertilizers to their crops due to poverty and other constraints, such as limited access to credit for agricultural inputs and high fertilizer prices (Chianu *et al.*, 2012; Tadele, 2017; Onyango *et al.*, 2021). For Hounnou *et al.* (2019), climate change-induced crop yield losses would reduce Benin's agricultural production by 4.4% by 2025. According to Gillespie *et al.* (2016), the exclusive use of certain mineral fertilizers can promote soil acidification and thus lead to lower productivity. Various authors such as Xin *et al.* (2020) and Zhang *et al.* (2020) have highlighted the need to promote adaptation guidance policies that focus on shifting farmers' paradigm towards more efficient, pro-environmental approaches.

Beyond creating an economy that is more resilient to the effects of climate change, adaptation strategies often have critically important secondary effects (IPCC, 2014b). These can be beneficial or costly. In this context, the remedy for low soil productivity lies in the introduction of various integrated soil fertility management techniques adapted to specific conditions (Soropa *et al.*, 2019). Existing literature indicates that the adoption of these farming strategies can improve the well-being of farmers. According to Wossen *et al.* (2019) and Anang et al. (2020), technology adoption influences farmers' production methods, increases agricultural output and consequently improves the family's general well-being. However, these benefits are not always perceptible in the short term, so farmers may be reluctant to adopt them. Some researchers, such as Das et al (2020), have estimated that the impact of technology adoption on increased income and well-being is not significant. Furthermore, farmers' adoption of integrated soil fertility management strategies is not a one-off, straightforward decision but a dynamic decision-making process in which they continually learn, improve or abandon over time (Chen *et al.,* 2021). Thus, many governments, with technical and financial support from international organizations, have invested in the development and dissemination of new soil and water conservation technologies (Abdulai and Huffman , 2014). Like other governments, Benin has developed and promoted several approaches to sustainable land management at agricultural level (Adekambi *et al*., 2021). These strategies include the use of improved plants, perennial legumes, crop residues, crop rotation, composting and microfertilizers. Farmers in this area are also developing cowpea and soybean cultivation, which they see as playing a significant role in improving soil fertility. These ISFM practices comprise a range of techniques (crop rotation, cover crops, composting, etc.) that interact in a complex way, making it difficult to attribute specific impacts to individual practices.

Several studies, both national and international, have addressed climate change adaptation strategies. But most of them have focused more on perception, vulnerability and factors determining the adoption of climate change adaptation strategies (Ouedraogo, 2012; Bezu *et* al., 2014; Sorgho *et* al., 2020; Basse *et* al., 2022). Few have addressed the impact of the adoption of integrated soil fertility management strategies in relation to the income of maize and soybean farmers in Benin. Challenges such as climate change, degradation of arable land, economic fluctuations and natural resource limitations (land, water, etc.) call for an assessment of the impact of these approaches, which integrate traditional practices with modern innovations to ensure sustainable, resilient agriculture in the western Atacora region. Impact assessment consists, on the one hand, in assessing quantitatively or qualitatively the long-term changes that have occurred as a result of the innovation and, on the other, in verifying that these are indeed attributable to the innovation and not to other events, as Devaux-Spatarakis and Quiedeville (2018) point out. However, these impacts of ISFMS practices can be affected by socio-economic factors such as access to markets, agricultural policies and available resources, making it difficult to assess their direct effects. An evaluation of these practices would highlight their effect on the agricultural income of the households that adopt them, in order to adjust them and promote sustainable and effective agricultural strategies in the region. The present research is part of this dynamic, attempting to assess the impact of these integrated soil fertility management strategies on the income of corn and soybean producers in northern Benin.

2. MATERIAL AND METHOD

2.1 Study area

This research was carried out in northern Benin, more precisely in the Atacora-West region, which includes the townships of Boukombé, Cobly, Matéri and Tanguiéta. This area is dominated by the Atacora mountain range, with an average altitude of 700 meters and the highest peak at Boukombé at 835 meters. This rugged geography contributes to a scarcity of agricultural land. According to Kombienou *et al.* (2020), the rugged landscape leads to significant soil degradation through erosion, making the land less fertile and less suitable for agriculture. Land degradation is taking a worrying turn for the worse due to demographic pressure, low use of soil conservation practices and increasing climatic variability (Kombienou *et al*., 2020). This is why the area was chosen for the present study.

Figure 1: Study area location [original picture]

2.2 Sampling and data collection

For the purposes of this research, the size of the target population is unknown. It has been determined using an approximation of the normal distribution law through the formula of (Dagnelie, 1998).

$$\boldsymbol{n} = \frac{P_i\ (1 - P_i)U^2_{1-\frac{\alpha}{2}}}{d^2}$$

With

- $n =$ sample size;
- α value of the random normal variable for a probability value at the threshold of $\alpha = 0{,}05$;
- $U_{1-\frac{\alpha}{2}} = 1{,}96$
- $U^2_{1-\frac{\alpha}{2}} = 3{,}84$
- $P =$ Proportion of target producers growing corn and soybeans in the locality;
- $d =$ margin of sampling error (3 %)

The observation unit is made up of corn and soybean producers in western Atacora. These two crops were selected because of their predominance throughout the study area (DSA-BENIN, 2022). Four (4) villages per township were randomly selected. A total of 16 villages were selected. The sample size n is thus roughly equal to 1,040 corn and soybean producers. This sample was distributed within each district according to the demographic density of each village (INStaD, 2016).

2.3 Data analysis method

The instrumental variable method was chosen to estimate the impact of integrated soil fertility management strategies on the income of corn and soybean growers. It should be remembered that, if adoption choices are either substitutive or complementary, the literature recommends using the instrumental variable method to avoid selection bias, and to identify and estimate impact consistently (Heckman et al., 1997). The "Local Average Treatment Effect", which is the average impact for the sub-population of potential adopters, is estimated using regression models. Two estimators of the instrumental variable are often calculated. According to Ndiaye *et al.* (2018), the first is that developed by Wald (non-parametric method), which requires only the outcome indicator y, the "adoption status" variable A and the instrument z. The second estimator of the instrumental variable is proposed by Abadie (2003), and is nothing other than the generation of the Wald estimator in the case where the instrument z is not totally independent of the potential outcomes y1 and y0, but will become so conditionally on the independent variables x that determine the outcome y. It is this latter estimator that is adopted in the present research. Since it is impossible to adopt an integrated soil fertility management strategy without being aware of the existence of at least one of the related practices (Diagne *et al.,* 2007), To= 0 for any producer, and the indicator variable for adoption status can therefore be written as follows: T= z Ti. Assuming that z is independent of the potential indicators T1, y1 and y0 conditional on the independent variables x for any function $g(y, T, x)$, there is an average impact estimator for the sub-population of potential adopters (LATE) which is given by the equation (Abadie, 2003):

$E[(y, T, x)/T_1 = 1] = \frac{1}{P(T_1=1)} E[k.\, g(y, T, x)]$ où k= 1- $\frac{z}{P\left(Z=\frac{1}{x}\right)}(1 - T)$ represents the weight that the value 1 takes on for potential adopters, and negative values if not. The conditional probability that lies $P(z = \frac{1}{x})$ will be estimated from a Logit model. This equation, named "Local Average Response Function (LARF)" by (Abadie, 2003), can be re-estimated by the following equation:

$E(\frac{y}{x}, T_1 = 1) = \alpha_0 + \alpha_1 T + \beta X + \gamma TX$ avec α ; β; γ parameters to be estimated and $LATE = \alpha_1 + \gamma X$.

2.4 Choice of variables, parameter and estimator

According to Ndiaye *et al.* (2018), the adoption of a climate change adaptation strategy by an individual corresponds to its use. In the present research, there are three adoption variables; that is, the application of at least one integrated soil fertility management practice. Let Tiz represent the results of potential adoption of at least one integrated soil fertility management practice, given that a binary instrument Z takes the value 1 when the farmer adopts one of the integrated soil fertility management practices and 0 if he does not adopt at least one integrated soil fertility management practice. Consequently, there are two adoption variables T1= 1 and To= 0, which mean respectively that an individual i adopts at least one integrated soil fertility management practice if he/she knows at least one of the following practices. In this case, the adoption result is given by $T = zT_1$ + (1-Z)T_0. Since it is not possible to adopt an integrated soil fertility management practice without knowing it, then T_0= 0 for all producers, and the adoption results are simplified T= zT1. Potential adoption in the sub-population of producers who adopt at least one integrated soil fertility management practice is given by T1= 1 and that of current adopters by D1= 1. With the potential treatment variables T1= 1 and T_0= 0, developed by (Angrist and Imbens, 1995) which divide populations into four groups according to their treatment compliance status: the obedient (those with T1= 1 and To= 1), the always takers (those with T1= =To= 1), the never takers (those with T1= T_0= 0), and the defaulters (those with T1= 0 and To= 1). The covariate vectors chosen remain the same as those used in the chapter based on the estimation of the level of adoption. It should also be remembered that the outcome indicator measured by the study is income from maize and soybean production in the study area. To measure impact, the outcome variable is the net income of the head of the household producing corn and soya.

2.5 Method of calculating farm income for corn and soybean growers

With regard to income, it was decided to calculate the net income per hectare of each farmer (i) who adopts one of the strategies contained in each of classes 1 and 2. This choice is justified by the fact that in Benin, the perfect functioning of the land market is not effective in most regions of Benin (Sodjinou and Hounkponou, 2019). Any production process involves input and output flows. Thus, net farm income (REVNET) is the difference between the value of crop production (outputs) and the associated costs (inputs). It is given by the following formula:

REVNET= PB - CT avec CT= CV + CF + MO ; the total costs are made up of variable costs (CV), fixed costs corresponding to equipment depreciation, and salaried and family labor (MO). The cost of salaried labor corresponds to the amount of money actually spent by the producer. The cost of family labor is obtained by multiplying the quantity (in man-days) by the average unit selling price of wage labor in the study area. It should be noted that in the present study, the adopters' net farm income is assimilated to the net margin from the production and sale of corn and soya.

3. RESULTS

3.1 Producers' average income per hectare according to adoption of ISFM strategies

The table of descriptive statistics for corn producers' incomes provides a detailed view of the distribution of income per hectare between the two groups, adopters and non-adopters of advanced adaptation strategies. A first striking observation is the significant disparity in income distribution between these two groups. Adopters have a higher proportion in the higher income categories, with 16.9% of adopters generating an income of less than 10,000 F, compared with 54.1% of non-adopters in the same category. Remarkably, adopters also dominate the higher income categories, with an increasing proportion as income per hectare rises. For example, 58.3% of adopters generate net farm incomes of between 10,000 F and 100,000 F, while this proportion drops significantly to 45.9% among non-adopters. Thus, these results suggest a positive correlation between the adoption of adaptation strategies and the income level of maize producers, reinforcing the idea that integrated management practices can have a positive impact on the profitability of corn farms.

In addition, the mean figures and standard deviations provide a quantitative comparison between the two groups. Adopters show a significantly ($p < 0.05$) higher average of 64,355.27 francs per hectare, while non-adopters show a significantly lower average of 14,342.73 francs per hectare. These results highlight not only a significant difference in averages, but also a notable dispersion in the incomes of non-adopters. A comparison of minimum and maximum incomes reinforces this observation, showing that adopters achieve much higher income levels than their non-adopting counterparts.

Similarly, soybean producers adopting ISFM strategies have a higher proportion in the higher income categories. For example, 39.6% of adopters generate incomes between 100,000 F and 200,000 F per hectare, compared with only 19% of non-adopters in the same bracket. Similarly, adopters dominate the higher income categories, with higher proportions as income per hectare increases. The results also show that adopters of advanced farming practices in this speculation have a statistically ($p < 0.05$) higher average of 127,355.13 F per hectare, compared with the lower average of 73,780.45 F per hectare among non-adopters. These data thus highlight a positive correlation between the adoption of ISFM strategies and the level of farm income of soybean producers.

Results for both crops, corn and soybean, suggest that the adoption of integrated management strategies has a significant impact on producers' incomes. Adopters of these practices not only show higher proportions in the higher income categories, but also substantially higher average incomes per hectare than non-adopters. These observations underline the importance of implementing farming practices focused on agricultural diversification and resilient agroecology to improve farm profitability, which could have both positive economic and environmental implications.

Table 1: Income per hectare for producers according to adoption of integrated management strategies

Crops	Total income per hectare	Groups			
		Adopters		Non adopters	
		Total	%	Total	%
Corn	< 10000	118	16,9	20	54,1
	10000 ≤ Income < 100000	407	58,3	17	45,9
	100000 ≤ Income < 200000	147	21,1	00	00
	200000 ≤ Income < 300000	21	3,01	00	00
	300000 ≤ Income < 400000	02	0,28	00	00
	Income ≥ 400000	03	0,43	00	00
	Total	698	100	37	100
	Average ± Standard deviation	64 355,27 ± 61 422,79		14 342,73 ± 12 531,89	
	Minimum	175		1 708,33	
	Maximum	333 680		49 375	
Soybean	< 10000	01	0,2	03	14,3
	10000 ≤ Income < 100000	201	40,8	13	61,9
	100000 ≤ Income < 200000	195	39,6	04	19
	200000 ≤ Income < 300000	82	16,6	01	4,76
	300000 ≤ Income < 400000	11	2,23	00	00
	Income ≥ 400000	03	0,6	00	00
	Total	493	100	21	100
	Average ± Standard deviation	127 355,13 ±84 768,57		73 780,45 ± 57 956,36	
	Minimum	8000		3000	
	Maximum	556109		213000	

3.2 Estimation of the coefficients of the instrumental logistic model

Sargan's over-identification test yielded a (p-value > 0.05). This high p-value (greater than 0.05) indicates that we cannot reject the null hypothesis of instrument validity. In other words, there is insufficient evidence to conclude that the instruments are correlated with model error. This suggests that the instruments are probably exogenous and that their use is appropriate. Thus, the use of SGIFS as an instrument is valid. Instrument validity also confirms that the model is well specified in terms of instruments, indicating that the instrumental variable method is correctly applied.

3.2.1 Corn producers

The instrumental variable model for maize production shows significant results for several key variables, indicating their impact on the likelihood of adopting integrated management strategies (Table 01). Among the influential variables, farmers' level of education proves to be a crucial factor. Producers with primary or secondary education have a significantly higher probability of adopting ecological farming practices than those with no formal education. This finding underlines the importance of education in decision-making related to the adoption of sustainable farming practices.

Similarly, literacy emerges as another significant determinant. Literate farmers show a higher probability of adoption, reinforcing the idea that the ability to read and understand relevant information can play a crucial role in the acceptance of new farming practices. The area under maize cultivation by farmers was also a significant variable, with a larger area associated with a lower probability of adoption. This relationship could indicate that smaller farmers are potentially more open to experimenting with new practices, while larger farmers would face logistical challenges or reluctance to change.

Furthermore, the training variable plays a crucial role in the adoption of integrated management strategies. Farmers who had benefited from training had a significantly higher probability of adopting these practices, underlining the importance of awareness-raising and continuing education in promoting the adoption of sustainable agricultural practices. Finally, the quantity of mineral fertilizers (NKP and urea) used also emerges as a significant factor, underlining the direct impact of these inputs on farmers' decision to adopt diversified farming practices. These results provide essential information to guide intervention and awareness-raising efforts aimed at maximizing the adoption of sustainable and diversified farming practices among corn farmers.

3.2.2 Soybean producers

The results of the instrumental variable model for soybean cultivation reveal that of all the variables examined, only primary and secondary education levels show significant effects on the adoption of diversified and agroecological strategies (Table 02). Farmers with higher levels of primary and secondary education are more likely to adopt strategies based on diversified agriculture than those with university education. This suggests that education plays a key role in the decision to adopt diversified or ecological farming practices.

It is worth noting that other variables, such as age, gender, farming experience, access to credit, household size, farm assets, total crop area, training, use of mineral fertilizers and use of organic matter did not show significant effects on strategy adoption. This suggests that, for the soybean crop, the choice to adopt integrated management practices is probably influenced by other factors specific to this crop.

Table 2: Factors determining the impact of adopting integrated management strategies for corn production

Variables	Corn		Soybeans	
	Estimate	Std.error	Estimate	Std.error
Intercept	2,56e+01	1,29e+03	2,019e+01	1,118e+03
Age				
15-30	-2,02	1,31	4,523e-01	1,052
30-45	-1,38	1,20	4,274e-01	9,795e-01
Man	-0,773	8,35e-01	5,050e-01	6,752e-01
Instruction				
Primary	2,48	8,83e-01	2,375	1,11
Secondary	3,55	1,06	2,292	1,214
Academic	1,64	1,34	0,837	1,19
Literacy	-2,06	0,92	-1,693	1,01
Association	-0,253	0,55	-0,853	0,738

Variables	Corn		Soybeans	
	Estimate	**Std.error**	**Estimate**	**Std.error**
Outreach	0,653	0,92	-1,376	0,929
Experience				
0-10	-2,02e+01	1,29e+03	-1,76e+01	1,12e+03
10-20	-2e+01	1,29e+03	-1,76e+01	1,12e+03
20-30	-2,03e+01	1,29e+03	-1,76e+01	1,12e+03
Credit access	-6,95e-01	0,52	-4,76e-01	6,05e-01
Household size	3,61e-02	0,11	4,75e-02	1,36e-01
Farm assets	-2,03e-02	0,17	8,40e-02	2,42e-01
Corn acreage	-4,24e-01	0,22	-3,85e-01	2,86e-01
Training	-2,45	0,83	-4,88e-01	8,02e-01
Mineral fertilizers	1,83e-03	1,01e-03	4,59e-04	2,11e-03
Organic compost	-4,58e-03	3,42e-03	7,54e-02	2,32e+01
Herbicides	9,55e-02	1,25e-01	2,66e-01	2,74e-01
N	**735**		**514**	
Null deviance	**293.29**		**175.43**	
Residual deviance	**185.31**		**129.07**	
AIC	**227.31**		**171.07**	

4. DISCUSSION

Several authors have shown that the adoption of integrated soil fertility management strategies is becoming increasingly important for farmers in sub-Saharan Africa in general, and in Benin in particular (Bezu *et al.,* 2014; Ojo *et* Baiyegunhi, 2020; Adekambi *et al.*, 2021b; Wang *et al.*, 2021; Sisay *et al.*, 2023b). These strategies have a positive or negative impact on farmers' income and economic profitability. The local average treatment effect on adopters and t-test indicated that the difference between the average net farm income of adopters of integrated soil fertility management (ISFM) strategies and non-adopters was significant. The difference between the average net farm income of ISFM adopters and non-adopters was significant (510005.33F) and statistically different from zero. These results corroborate those obtained by Oduniyi and Tekana (2021), Sissoko *et al*. (2023) and Sisay *et al.* (2023c), who found that the adoption of sustainable agroecological practices positively impacted the net farm income of small-scale corn producers in Africa. Furthermore, the results also show that adopters of practices based on diversification and resilient agroecology at the level of each of the speculations display a statistically ($p < 0.05$) higher average of 68,405.72 F and 127,355.13 F per hectare, compared with the lower averages of non-adopters. These results are therefore in line with those of Oduniyi *et al.* (2021), who showed that the average net farm income of farmers who adopted sustainable land management strategies was significantly higher than that of non-adopters.

As a reminder, resilience diversification encompasses strategies linked to crop rotation, the use of organic manure, the practice of fallowing, the development of intercropping between cereals and legumes, the optimal use of chemical fertilizers, etc. These diversification and agro-ecological strategies have also had a positive impact on the income of adopters, both in terms of corn and soybeans. These diversification and agro-ecological strategies have also had a positive impact on the income of adopters of both corn and soybean, even if the average income per hectare appears low.

These results support those obtained by Adekambi *et al.* (2021a) and Kichamu *et al.* (2021), according to which there is interdependence and complementarity between the different diversified and agroecological strategies. This is all the more true as the model results underline the positive impact of chemical fertilizers on corn production.

The results of the model estimation revealed that producer age, farm size, level of education, extension, training and association membership were factors influencing the adoption of IFMS and, in turn, producer income in Atacora-West in northern Benin. These results confirm those obtained by Sisay *et al*. (2023d), who reported that the level of education positively influenced the adoption of integrated management strategies and the average income of producers. This suggests that better-educated growers are more likely to adopt new ecological strategies in response to climatic variability. However, these results indicate that younger growers have significantly lower incomes than older growers; this is contrary to the findings of Adego *et al.* (2019). For the latter, age is positively correlated with productivity and therefore farm income. The association of age with productivity is therefore controversial in the literature. There is empirical evidence that crop productivity decreases with age, as older people may be risk averse and may have shorter planning horizons in cases where the benefits of adoption are not immediate (Asfaw *et al.,* 2016b). Consequently, a negative relationship between age and adoption could be found in the present research. Older farmers being used to conventional farming strategies are less inclined to adopt new practices (Adego *et al.,* 2019). Furthermore, farm size negatively influences the adoption of ISFM strategies; this is contrary to the results obtained by Ojo and Baiyegunhi (2020) and Antwi-Agyei *et al.* (2023b), who showed that the larger the farm size, the better the producers adopt new agricultural diversification strategies. The estimation of the instrumental variable model also revealed that household size and participation in training courses were factors that positively influenced the adoption of ISFM strategies and consequently the income of maize producers. This confirms the results obtained by Oduniyi *et al.* (2021) and Antwi-Agyei *et al.* (2023b), who concluded that household size and access to training and information positively influenced the adoption of climate change adaptation strategies and household income. Contrary to some authors (Akpo *et al*., 2016; Branca *et al.,* 2021) who have found that integrated soil fertility management practices improve agricultural productivity by only 25% and remain costly, the present research allows us to affirm that the combination of integrated soil fertility management practices in the face of climate improves yields and incomes of small rural households in the Atacora-Ouest region of northern Benin.

5. CONCLUSION

This research analyzed the impact of the adoption of integrated soil fertility management strategies on the income of corn and soybean farmers in Atacora-West in northern Benin. The instrumental variable model was used to analyze the impact and factors determining the adoption of diversification and agroecological strategies. The model highlighted the impact of ISFMS on the farm income of maize and soybean growers. This average net income was also influenced by several socio-economic factors. The data show a positive correlation between the adoption of integrated soil fertility management strategies and farmers' farm income. The main lesson learned is that it is possible to improve farm income and food security through integrated approaches to new climate strategies. In short, it is important that rural development players, particularly those in the corn and soybean sectors, take initiatives to implement concrete actions on integrated soil fertility management strategies. This means developing initiatives linked to access to training in sustainable agricultural practices and promoting the use of local resources and techniques adapted to specific soil and crop conditions, which are necessary to reduce the economic barriers to the adoption of ISFMS.

Authors' contributions: Dr BCR, conceived the idea and wrote the manuscript. In fact, he proceeded to treat and analyze the statiscal data collected in the field, using R software. Professor, VGF member of Economic and Social Dynamic Research Laboratory, read and approved the results of the study.

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