Factors Influencing Adoption of New Irrigation Technologies on Farms in Morocco: Application of Logit Model

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Abstract— *The objective of this article is to identify the determinants of the adoption of new irrigation technologies in Moroccan agriculture. The research is carried out on a sample of 82 farmers from the Souss-Massa region (Morocco). The results from the estimation of a binary logit model show that the variables: Age, level of education, non-farm income, perceived utility, possession of a computer, farm size, access to credit, ease of use, influence the probability of adoption of new irrigation technologies among farmers. The theoretical and managerial implications of this research are discussed.*

Keywords— Precision agriculture, technology adoption, irrigation, logit model, Souss-Massa region.

I. INTRODUCTION

In Morocco, the digitization of agriculture has started to gain more interest in recent years from various public and private actors. The last edition of the International Exhibition of Agriculture in Morocco (SIAM 2020) which was scheduled for April 2020 devoted its theme to technological innovations in agriculture, with the slogan "The future of agriculture lies in technological innovations ". The COVID-19 health crisis has reinforced this need to move to a digital economy, especially when this pandemic has crippled many sectors, threatening food security. The agricultural sector is then one of the most affected sectors. Empirical studies suggest that new technologies have positive agronomic, economic and environmental effects [1]. Experts now agree that technological innovation is an asset to save time and precision for the good of the farmer, the operation and the environment.

Today, Moroccan agriculture sector seems by far a sector where technological innovations are omnipresent. Unfortunately, we haven't the figures on the use of new technologies in the agricultural sector, but according to the World Economic Forum (WEF) in 2019, relating to information and communication technologies (ICT) at the global level, Morocco is ranked 100 out of 176 in the ICT Development Index, and 78 out of 139 in the NRI Index ranking (Networked Readiness Index), which gives us an idea of the level adoption of new technologies at the national level. At this level, precision agriculture (PA) appears to be a major asset for making agriculture an innovative and responsible sector. The literature indicates that PA technologies have one thing in common: optimizing agricultural production. PA technologies now allow farmers to apply the right dose of input at the right time, reduce the use of phytosanitary products, predict the outbreak of diseases in a plot, reduce energy consumption fossil fuel and accurately determine water requirements.

The Souss-Massa region, the Kingdom's main agricultural area, and one of the main centers of economic growth thanks to projects initiated under the Green Morocco Plan. However, agricultural activities are threatened by their dependence on water resources. With intensive use of irrigation gradually and dangerously depleting groundwater resources, the region's dam fill rate has fallen from 41.73 percent last year to 24 percent this year. The introduction of new precision farming technologies has become a necessity for a more rational use of natural resources.

The adoption of technologies by farmers is the starting point for agricultural development, of which farmers are the actors, and technologies are the tools of this development. Adoption in itself is a complex part of this subject. Previous studies show that the adoption of technology depends on many factors (socio-demographic, economic, institutional, ..), and the farmer is at the center of the decision to adopt and accept the technology. The reality is that Moroccan farmers are so attached to their habits and practices, and therefore they are used to the use of traditional techniques.

In this perspective, this work is positioned downstream of the decision to adopt new irrigation technologies (NT), it is intended to explain the adoption of NT from PA, by putting focus on three irrigation technologies, namely: Capacitive probes, weather stations, and mobile applications. Questions arise: On what can the adoption decision of the Moroccan farmer depend? Depending on the determinants of adoption, what may be the implications and challenges for the Moroccan agricultural sector? The interest of this research lies in the understanding of the factors which lead the farmer to the adoption of the NT which are essential at the same time for the decision makers, the diffusers of these technologies (companies), and for the researchers who study the determinants of growth. Interest in digitization, especially with the arrival of the COVID-19 pandemic, has only increased in recent times. The public authorities therefore need to understand the mechanisms of adoption by the farmer in order to be able to put in place a strategy for the development of digital agriculture.

II. THEORETICAL FRAMEWORK AND RESEARCH HYPOTHESES

The literature review allowed us to identify several variables that may influence the adoption of precision agriculture technologies. We have grouped these variables into four groups of explanatory variables: individual factors, organizational factors, environmental factors, and technological factors.

2.1 Individual factors

Age is identified as a determining factor in adoption. Older farmers tend to be conservative and reluctant to change and adopt technologies due to risk aversion [2] [3] explains that older farmers are more risk averse, less motivated to experiment with NT, less likely to be influenced by the benefits of NT. [4] explains that young farmers are more open to innovations and more likely to adopt new technologies. In the same way, [5] add that sometimes the adoption of technologies by older farmers is explained by the high investment costs, and that these farmers already have the means for their acquisition unlike the younger ones.

Hypothesis 1: Age has a negative effect on the adoption of new technologies.

The education level is highlighted by many authors as a determinant of the adoption of NT [5]–[7]. For example, [2] find that the adoption rate increases with the level of a farmer's education, especially if it’s advanced technology, and that learning is necessary for its use. The education level makes it easier for the farmer to use it, but also becomes someone more open to innovation.

Hypothesis 2: The education level has a positive effect on the adoption of new technologies.

On the other hand, the cost of acquisition has been closely linked in the literature to farm and non-farm income. Research results show that the higher the farm income, the more likely the farmer is to adopt new technologies [8]. The existence of off-farm income also increases the chances of adoption [9] [10] explains that for farmers with moderate income, non-farm income provides cash that can help the farmer learn NT. Access to off-farm income generating activities is generally associated with technology adoption [11] found that adoption has high costs, and that higher-income farmers are more likely to adopt them [12] showed that a 10% increase in income from agriculture was associated with a 9.2% increase in the chances of a producer adopting these technologies.

Hypothesis 3a: High agricultural income has a positive effect on the adoption of new technologies.

Hypothesis 3b: The existence of non-farm income has a positive effect on the adoption of new technologies.

On the other hand, farmers are more likely to adopt NT after seeing their usefulness in the field [3], [9]–[11], [13], [14]. For example, [15], in a study on the adoption of technologies in the dairy industry in Italy, he indicates that the demonstration of NT is practically done within the networks of farmers, which then pushes them to adopt the same technology [16] adds that cleaner production techniques (CPT) will only be adopted when farmers perceive their usefulness and the satisfaction of other farmers who have already adopted this technology.

Hypothesis 4: Perceived utility has a positive effect on the adoption of new technologies.

Another important factor that affects adoption is the attitude to risk. Some farmers prefer to work with the means at their disposal rather than invest in NT [8]. One of the reasons for this reluctance is uncertainty, first about the use of technology, and second about the economic return. For example, when the market price of agricultural products falls, farmers tend to invest less in capital (machine, innovation, etc.). For example, [10] points out that farmers who have less uncertainty about the economic return of NRVs are more likely to invest in these technologies. Complex technologies require additional investment in learning [9] adds that a modest level of skills and know-how negatively influence adoption. Its results show that technologies that require a lot of skill and technical know-how decrease the likelihood of their adoption.

Hypothesis 5: Risk attitude has a negative effect on the adoption of NT.

Computer use in farm management has been associated with the adoption of certain technologies such as the personal digital assistant (PDA) [17], or the Autosteer GPS guidance system [13] [17] explains that farmers who use computers in administrative management (for mail, invoicing, accounting, inventory and human resource management, etc.) may be more likely to adopt PA technology [5] postulate that farmers who are open-minded about technological advancement are also more supportive of technology adoption on their farms.

Hypothesis 6: Possession of a computer has a positive effect on the adoption of NT.

2.2 Organizational factors

Farm size is identified as a determinant of adoption. [6] explain that large farms are more complex to manage, NT have been shown to be effective in optimizing production and reducing costs [18] explain that the farm size is linked to the adoption of NT, as the farmer tends to devote some of his land to trying a NT first, unlike small farms. These findings align with several research studies on the adoption of PA technologies [4]–[6], [15], [19].

Hypothesis 7: The size of the farm has a positive effect on the adoption of new technologies.

On the other hand, [10] show that the lack of a title deed significantly decreases the likelihood of farmers adopting the technologies. This is because farmers with title deed are more likely to adopt practices that improve the soil compared to those who are in rental. Studies [12], [20] indicated that farmers who had obtained certificates of ownership felt more secure, which enabled them to make long-term investments. This is the case for example with drip irrigation; its non-adoption is most often linked to the rental status which does not benefit from subsidies.

Hypothesis 8: The absence of a title deed has a negative effect on the adoption of NT.

2.3 Institutional factors

Our exam of the literature showed the importance of the role by public services for encouraging the adoption of new technologies. It has been shown that awareness [21], [22], access to agricultural extension services [22], credit facilities and aggregation practice [7], [10], [18], [23] are essential to encourage the adoption of technological innovations [22] find that training and extension are means of raising awareness and supporting the adoption of watershed management practices [5] stress the importance of good advice, and offer the necessary information. The author points out that the lack of counseling and training is a barrier to adoption, and that internet availability alone is not a sufficient factor for farmers.

Hypothesis 9: The presence of a consulting service has a positive effect on the adoption of NT.

Farmers' access to credit services is identified as a determinant of the adoption, because bank credit allows farmers to have other financial resources, and therefore invest in new technologies. Several studies [7], [18], [23] conclude that farmers' access to credit services increases the likelihood of technology adoption [10] have shown that subsidies and taxation are tools for adopting new technologies [21] indicated that the adoption of green manure is strongly linked to certain government measures, such as subsidies for maintenance, reduction of tax for adopters, reduction of interest rate [23] show that the variable amount of subsidy is strongly correlated with the probability of adoption, the higher this amount, the greater the probability of adoption. In other words, the difficulty in accessing subsidies was associated with a relatively low adoption rate. The more difficult it is for farmers to access subsidies, the lower the likelihood of them adopting drip.

Hypothesis 10: Access to credit has a positive effect on the adoption of NT.

2.4 Technological factors

The cost of acquiring technology is often identified as a determinant of adoption [6], [7], [24]–[26] [5] point out that the majority of farmers are reluctant to introduce precision farming techniques mainly because of their high costs. Large farms are more likely to adopt precision farming technologies compared to small farms due to their financial capacity [10].

Hypothesis 11: The more the farmer perceives the cost of the technology, the lower the probability of adoption.

Ease of use is identified as an important factor in the adoption of PA technologies [21] find that farmers' intention to adopt EWS is influenced by perceived ease of use, subjective norms and perceived behavioral control. The authors show that farmers' perception of the ease of use of PA technology has a significant impact on its adoption. A farmer who perceives PA technology as complex or difficult to use is therefore less likely to adopt it [27].

Hypothesis 12: The perception of ease of use has a positive effect on the adoption of new technologies.

The figure below summarizes the variables that may explain the adoption of NT.

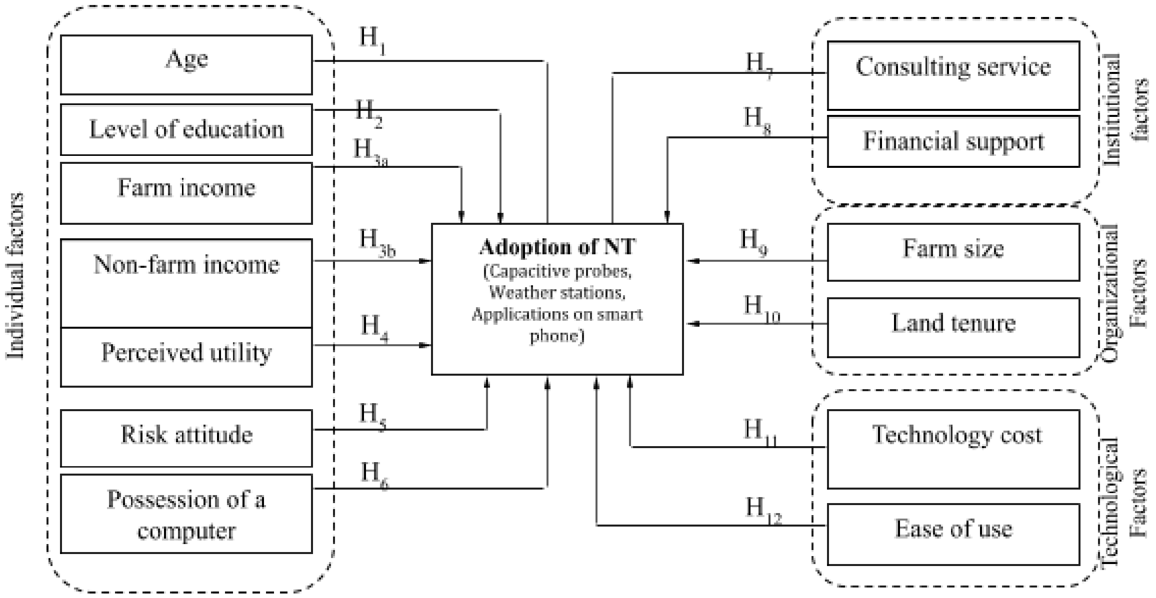

FIGURE 1: Proposed model to explain adoption of NT.

III. METHODOLOGY

In this section, we detail the methodology of the empirical study. First, we specify the research approach (3.1), the nature of the sample and the data collection method, then (3.2) we present the data analysis procedure (3.3).

3.1 Justification of the research approach

The already significant literature on the variables used in this research invited us to have a hypothetico-deductive approach. Indeed, [28] recall that when theoretical work provides enough knowledge on the phenomenon studied and lays intellectually consistent and empirically relevant theoretical bases, the deductive approach is desirable.

3.2 Sample and data collection

Our data collection was carried out in the region of Souss-Massa (Morocco). To collect the data, we opted for remote surveys during the month of April 2020. This choice is justified because of the health crisis (COVID-19), and the obligation of social distancing. A questionnaire was developed based on our theoretical framework. It is composed of four parts: Individual factors, organizational factors, institutional factors and technological factors. Table 1 gives an overview of all the variables, and the response methods.

We contacted the public services and companies supplying new technologies in the region to obtain the telephone directories of the farmers. A telephone directory of 130 farmers has been established. A pre-test was carried out on a sample of 10 farmers to test and adapt the questionnaire.

In order to be able to effectively explain the phenomenon studied, a large sample is needed. Otherwise, the results will be of limited scope, which could constitute a limit to the model used. Concretely, the rule is that for each explanatory variable, it will take at least between five to ten observations. In our case, we have retained thirteen variables, that is to say a minimum of total observations ranging between [65; 130[. And since we have made 82 observations, the minimum number required for logistic regression modeling is reached. While such a sample doesn't make it possible to ensure the representativeness of the results obtained and to seek external validity, it already leaves the possibility of improving our knowledge of the process of adoption of NT by farmers.

TABLE 1
BRIEF DESCRIPTION OF VARIABLES USED IN THE LOGIT REGRESSION MODEL

Variable	Type	Description
Adoption of NT	Binary	1 = Yes ; 0 = No
Age	Categorical	1 = <45 ; 2 = 45-60 ; 3 = Plus 60
Level of education	Categorical	1 = Illiterate ; 2 = Primarylevel ; 3 = Secondarylevel ;4 = ≥ Bac+3
Farmincome	Continuous	-
Non-Farmincome	Binary	1 = Yes ; 0 = No
Perceived utility	Scale	1 = Not at all useful; 2 = Not useful 3 = Useful; 4 = Very useful
Risk attitude	Scale	1 = Not at all risky; 2 = Not risky; 3 = Risky; 5 = Very risky
Possession of a computer	Binary	1 = Yes ; 0 = No
Farm size	Categorical	1= <20 ; 2= 20 – 50 ; 3= 50 – 100 ; 4= >100
Land tenure	Binary	1 = Property ; 0 = Location
Financial support	Binary	1 = Yes ; 0 = No
Consulting survice	Binary	1 = Yes ; 0 = No
Technologycoast	Scale	1 = Not at all high; 2 = Not high 3 = High; 4 = Very high
Easy of use	Scale	1 = Very easy; 2 = Easy; 3 = Difficult; 4 = Very difficult

3.3 Data analysis procedure

The adoption of new technologies is a YES or NO type choice, which refers to the Probit and Logit models which have been widely developed and used to study choice problems with binary dependent variables [29], [30].

The logit model is written as follows: $(\boldsymbol{Y}|\ \boldsymbol{X})$ = P (Y=1| X) =L($\mathbf{X'\beta}$)

Estimation in such a nonlinear model is more often based on the principle of maximum likelihood than on the principle of least squares. By the principle of maximum likelihood, we seek to calculate the value of the parameter β which maximizes the function L($\beta|Xn$). It is equivalent to find the parameter which maximizes the log-likelihood: l|Xn=ln L(β|Xn)

$$= \sum_{i=1}^{n} [Y_i \ln G(X'_i\beta) + (1 - Y_i) \ln\{1 - G(X'_i\beta\}]$$

IV. RESULTS AND DISCUSSIONS

In this part, we present a descriptive overview of our sample (4.1), and then we present the results of the research hypothesis tests (4.2).

4.1 Descriptive overview of the sample

All the agricultures in our sample are managed by men, with an average age of 45 years.

The distribution of farmers in our sample by educational level shows that 35% of farmers have a higher education than BAC + 3. 42% are illiterate, and 23% have primary and secondary levels.

Regarding the size of the farms surveyed, our sample is made up of farms with an area ranging from 2 ha to 800 ha. Almost 40% of the farms in our sample have a size between 5-20ha, 15% have a size between 20 and 50ha; 15% are between 50 and 100ha, and 30% are over 100ha.

For the type of crop, market gardening is identified as the main crop in 62% of the farms in the sample, against 38% for citrus.

For land tenure, rental is dominant; it represents 57% of the farms in our sample. The rest are private property.

Finally, concerning the direction of production, 43% of the production of farms is intended for the local market, 40% is reserved for export, and 17% of production is intended for processing.

4.2 Estimate of the Logit model of adoption of new technologies

Our dependent variable is NT adoption, which is a binary variable taking the value 0 if the farmer doesn't adopt any technology, versus the value 1 if the farmer adopts the three technologies pack aforementioned. The results of the estimation of the binary logistic model are presented in Table 2.

The model fits well, having fulfilled the conditions of a predictive model. Based on the forward selection method, the best fit model was created in six steps with the likelihood ratio test. Nagelkerke's R^2 of 0.52 indicates a satisfactory relationship between the independent variables and the dependent variable. R^2 logit is 0.39, which means that almost 40% of the variability in the probability of adoption is explained by the variables of the final model. We can then look at the Hosmer-Lemeshow test. This indicates whether there is a significant difference between the predicted and observed values. The ranking table shows that our model is able to correctly predict 73.4% of adoption cases, indicating a good fit of the model. Following the ascending method (Forward selection), and the likelihood ratio test (LR), only significant variables appear in the final model. The influence of the variables is expressed by the values of the logistic coefficients (B), and the odds-ratios are expressed by E [B].

TABLE 2
RESULTS FOR NT ADOPTION TESTED BY BINARY LOGISTIC REGRESSION

Variable	Coefficient B	Std, Error	Wald X²	Prob.	E[B]
Age	-0,221	0,091	5,90	0,007***	0,802
Level of education (≥ Bac+3)	0,68	0,027	634,29	0,0012***	1,974
Non-Farmincome(1 : Yes)	0,1823	0,054	11,40	0,012*	1,200
Perceived utility	0,1118	0,068	2,70	0,015*	1,118
Possession of a computer(1 : Yes)	0,096	0,047	4,17	0,0501*	1,101
Farm size (>100ha)	0,177	0,051	12,04	0,000***	1,194
Farm size ([50 – 100ha])	0,089	0,021	17,96	0,028*	1,093
Financial support(1 : Yes)	-0,118	0,045	6,88	0,031*	0,889
Easy of use	0,168	0,021	64,00	0,000***	1,183
C	5,501	1,124	23,95	0,021*	244,937

Note : Method: forward selection (likelihood ratio), dependent variable: NT Adoption (0 = no adoption; 1 = adoption of NT); original model (-2Log-Likelihood): 530,107; Full model (-2 Log-Likelihood):324,710; Chi squared: 205,389; R² (Cox and Snell) = 0.355; R² (Nagelkerke) = 0.523; Hosmer–Lemeshow test: Chi squared = 11,489, df = 5, Sign. 0,176 (n.s); R²logit = 0.399 Classification (model): 74.5%; N = 82; *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001.***

The age of the farmer negatively affects the adoption of new technologies ($\beta1 = -0.221$, $p < 0.01$). A farmer who belongs to the age group of 60 and over decreases the probability of adoption by 22.1%. This result is consistent with the literature. For example, [4] find that the age of the farm manager has a negative effect on the likelihood of adopting irrigation technologies. For his part, [3] explain that older farmers are more reluctant to change, less motivated to experiment with new technologies, less likely to be influenced by the benefits of new technologies. Hypothesis H_1 is validated.

The level of education of the farm manager has a positive impact on adoption ($\beta2 = 0.68$, $p < 0.01$). According to the results obtained, a farmer with a level of education of Bac + 3 or more, increases the probability of adoption by 68% compared to an illiterate. The latter is half as likely as the former to adopt NT. This result is consistent with the results of several studies [5]–[7], [31]. For example, [2] find that the adoption rate increases with the level of education of the farmer, especially if the technology is advanced, and learning is necessary for its use. The H_2 hypothesis is validated.

On the other hand, we didn't find a significant link between farm income and adoption. This result can be explained by the fact that the farmers in our sample haven't sufficient income to invest in or experiment with new technologies. Hypothesis H_{3a} is rejected. On the other hand, the existence of a non-agricultural income (or a secondary activity) increases the probability of adoption by 18.23% compared to a farmer who doesn't have a non-agricultural income ($\beta 5 = 0.1823$, $p < 0.10$). This result is similar to that of [9] who point out that the existence of a non-agricultural income increases the chances of adopting NT. Indeed, [10] explain that for farmers with moderate income, off-farm income provides cash that can help the farmer to acquire new technologies. The H_{3b} hypothesis is validated.

For perceived utility, the results of the estimate show that it has a positive effect on adoption ($\beta 5 = 0.1118$, $p < 0.05$). This result is consistent with several studies, the authors agree that farmers are more likely to adopt new technologies after seeing their usefulness [8], [13]–[15]. Hypothesis H_4 is validated.

As for Risk Attitude, we didn't find a significant link with adoption. In the literature, it's stated that risk aversion is often linked to the cost of investing in NT. Indeed, an investment in drip or in the use of drones requires a significant budget. In our study on the adoption of NT (capacitive probes, weather station, applications on smart phone), their costs aren't high, moreover there is the possibility of reselling them on the second-hand market. Hypothesis H_5 is rejected.

On the other hand, having a computer slightly affects adoption ($\beta 5 = 0.0122$, $p < 0.05$). The probability of adoption increases by 1.22% if the farmer already has a computer before the adoption. This result is similar to that of [13], who find that computer use in farm management is correlated with the adoption of certain technology (such as the autosteer GPS guidance system). Computer use is one indicator that shows farmers are open to technology. As pointed out [5], farmers who are open-minded about technological progress are also more favorable towards technology adoption. Hypothesis H_6 is validated.

As for the size of the farm, the results from the model estimate show that this has a positive impact on the adoption of technologies. However, this positive effect is not felt in the same way depending on the area class. Indeed, farms whose size is between 50 and 100 hectares, increase the probability of adoption by 8.9% ($\beta 5 = 0.089$, $p < 0.01$), while farms whose size is more than 100 hectares increase the probability adoption rate of 17.7% ($\beta 5 = 0.17$, $p < 0.01$) compared to the area of less than 20 ha. This result is consistent with several studies [10], [13], [15]. This is mainly due to the fact that large farms are more complex to manage, hence the need to use new technologies to optimize production and reduce costs. Hypothesis H_7 is validated.

The results of our estimations didn't establish a significant association between the land tenure variable (property title) and adoption. This can be explained by the type of NT in question. In fact, almost half of the farmers in our sample own their land. Studies [20], [26] have shown that farmers who have ownership certificates felt more secure to invest in NT, but it also depends on the nature of this investment, particularly if it's a long-term investment. As in the case of drip, which requires significant investment, which often farmer owners who adopt NT. Hypothesis H_8 is rejected.

Although agricultural advice also has a positive impact on the adoption of NT [5], [18], [32], our results didn't lead to a meaningful relationship. This can be explained by the council's goals in relation to digitization and the introduction of NT. We questioned the farmers whether they had participated in training or awareness-raising workshops on NT. It turned out that the themes discussed during these meetings are far from NT, they often relate to other agricultural activities other than NT. Hypothesis H_9 is rejected.

Although farmers' access to bank credit services is identified as a determinant of adoption [7], [18], [23]. This finding isn't validated in the context of our study. Indeed, our results show rather that farmers who have benefited from a bank loan are less likely to adopt NT ($\beta 10 = -0.118$, $p < 0.05$). Having a bank loan lowers the probability of adoption by 11.8%. This can be explained by the fact that the farmers who applied for credit, other things being equal, is a sign that they aren't already in good financial health. Hypothesis H_{10} is validated. For grants, they are usually intended for specific activities, other than purchasing NT from precision agriculture. The farmers who declared that they had received financial support in the form of a subsidy specified that the financial support was intended for basic equipment (tractors, plows, fertilizer spreaders, seed drills, combine harvesters, mower binders).

Regarding the Cost of the technology, the results of the estimates show that it hasn't significant effect on adoption. According to our interviews with the suppliers of NT in the Souss-Massa region, they testify that the main obstacle to the non-adoption of new technologies by Moroccan farmers isn't the cost, but rather it is due to attitudes and practices with which farmers are familiar. Although in many studies on the adoption of new technologies, the cost of the technology is often linked to the decision to adopt. However, in our opinion, it depends on the cost of the technology. A technology, the cost of which is high, will make the farmer hesitate to acquire it. Hypothesis H_{11} is rejected.

Finally, Ease of use has a positive effect on adoption ($\beta 9 = 0.168$, $p < 0.001$). A farmer who perceives a technology as difficult to use has less chance of adopting it compared to a farmer who perceives use as easy. This result can be explained by the fact that a third of the farmers in our sample have a BAC+3 and above. The level of education plays an important role in the use of NT, it would be easier for educated farmers to use technology compared to illiterate farmers. Hypothesis H_{12} is validated.

V. CONCLUSION

The objective of this article was to study the determinants of the adoption of NT. Based on the existing literature on the subject, a theoretical framework was developed. To test this theoretical framework, we relied on a sample of 82 farmers from the region of Souss-Massa (Morocco). The results from the estimation of a binary logit model show that the variables : Age, education level (≥ Bac+3), non-agricultural income, perceived utility, possession of a computer, farm size, credit access, ease of use, influence the probability of adopting NT among the farmers. To our knowledge, there's no empirical work on NT adoption in Morocco. The results of this study provide some answers to the adoption of NT by Moroccan farmers. They can be useful for public authorities and companies providing NT to set up strategies to promote the digitalization of the Moroccan agricultural sector.

The low education level among farmers requires efforts in terms of training, supervision and monitoring. Indeed, the technologies that fall within the scope of PA require learning which would only be possible if the farmer is able to understand their operation (reading a user manual or a display screen, entering data, settings, etc.). As our results show, the education level can make it easier or harder to use a technology. As the literature states, a technology could be adopted even if the farmer perceives the difficulty of using it. Studies show that farmers' perception of the ease of use of PA technologies has a significant impact on its adoption. A farmer who perceives PA technology as complex or difficult to use would therefore be less likely to adopt it. In the short term, it isn't possible to increase the education level of farmers so that they can fully understand their benefits, however, the public authorities can, therefore, act on building skills and knowledge- do this through training workshops and the provision of extension services that could equip farmers with the skills needed for NT acceptance and adoption.

Risk aversion can be overcome by improving the perceived usefulness of new technologies by farmers. This is important because farmers tend to ignore the benefits of using precision technologies [31]. Governments can then encourage farmers to use NT by demonstrating their usefulness. This can be done in collaboration with private companies, suppliers of these technologies, through the organization of demonstration workshops.

However, based on our knowledge of the field, certain variables whose effects turned out to be insignificant. These results should be interpreted with caution. For example, we didn't establish a significant link between land tenure and the likelihood of adoption. In Morocco, agricultural development faces problems of various kinds, but land in rural areas is often taken to be the main cause. Indeed, the land structures, the land status and the mode of access to land are taken to be the major constraint and the most important blocking factor to private agricultural investment, a real engine of agricultural development. The collective lands in their current forms, are considered on the basis of assumptions, as major obstacles to agricultural development, because they don't provide the conditions of security and stability necessary for agricultural intensification and development. private investment. Nationally, 70% of farms have less than 5 ha, and only accumulate 24% of the utilised agricultural area (UAA). This specificity of the size of farms can pose a serious problem for the implementation of an agricultural innovation strategy.

This study isn't without its limitations. As with all cross-sectional analyzes, it's difficult to test causalities even if they remain theoretically justified. Indeed, the expression "cross section" is used when the dependent and independent variables are measured on the same date. In this case, the results obtained do not always allow the identification of causal relationships. Also, the data collection was done remotely during the health crisis (COVID-19), which didn't allow us to collect more information.

In order to broaden our understanding of the NT adoption process among farmers, it would be interesting to integrate other variables into the predictive model, such as the orientation of production (local market vs export), the type of culture. Interactive effects are also necessary to better understand adoption. For example, studying the joint effects of educational level with ease of use, and farm size with type of crop on adoption.

Finally, digitization has now become an imperative in all sectors of the economy, including agriculture. COVID-19 will certainly accelerate this drive for modernization, but its success begins with an understanding of the mechanisms that lead the farmer to accept and adopt new technologies.

REFERENCES

[1] T. Koutsos et G. Menexes, « Economic, agronomic, and environmental benefits from the adoption of precision agriculture technologies: A systematic review », *Int. J. Agric. Environ. Inf. Syst.*, vol. 10, n° 1, p. 40-56, 2019, doi: 10.4018/IJAEIS.2019010103.

[2] A. R. Kaliba, R. J. Mushi, A. G. Gongwe, et K. Mazvimavi, « A typology of adopters and nonadopters of improved sorghum seeds in Tanzania: A deep learning neural network approach », *World Dev.*, vol. 127, 2020, doi: 10.1016/j.worlddev.2019.104839.

[3] P. Brown, A. Daigneault, et J. Dawson, « Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture », *J. Environ. Manage.*, vol. 231, p. 110-120, 2019, doi: 10.1016/j.jenvman.2018.10.018.

[4] M. Paustian et L. Theuvsen, « Adoption of precision agriculture technologies by German crop farmers », *Precis. Agric.*, vol. 18, n° 5, p. 701-716, 2017, doi: 10.1007/s11119-016-9482-5.

[5] M. Reichardt et C. Jürgens, « Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups », *Precis. Agric.*, vol. 10, n° 1, p. 73-94, 2009, doi: 10.1007/s11119-008-9101-1.

[6] M. J. Carrer, H. M. de Souza Filho, et M. O. Batalha, « Factors influencing the adoption of Farm Management Information Systems (FMIS) by Brazilian citrus farmers », *Comput. Electron. Agric.*, vol. 138, p. 11-19, juin 2017, doi: 10.1016/j.compag.2017.04.004.

[7] B. A. Gyata, « Comparative assessment of adoption determinants of electronic wallet system by rice farmers in Benue and Taraba states, Nigeria », *Food Res.*, vol. 3, n° 2, p. 117-122, 2019, doi: 10.26656/fr.2017.3(2).132.

[8] N. J. Miller, T. W. Griffin, I. A. Ciampitti, et A. Sharda, « Farm adoption of embodied knowledge and information intensive precision agriculture technology bundles », *Precis. Agric.*, vol. 20, n° 2, p. 348-361, 2019, doi: 10.1007/s11119-018-9611-4.

[9] S. K. Ng'ang'a, D. A. Jalang'o, et E. H. Girvetz, « Adoption of technologies that enhance soil carbon sequestration in East Africa. What influence farmers' decision? », *Int. Soil Water Conserv. Res.*, nov. 2019, doi: 10.1016/j.iswcr.2019.11.001.

[10] A. P. Barnes *et al.*, « Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers », *Land Use Policy*, vol. 80, p. 163-174, janv. 2019, doi: 10.1016/j.landusepol.2018.10.004.

[11] T. W. Griffin, N. J. Miller, J. Bergtold, A. Shanoyan, A. Sharda, et I. A. Ciampitti, « Farm's sequence of adoption of information-intensive precision agricultural technology », *Appl. Eng. Agric.*, vol. 33, n° 4, p. 521-527, 2017, doi: 10.13031/aea.12228.

[12] D. M. Lambert, K. P. Paudel, et J. A. Larson, « Bundled adoption of precision agriculture technologies by cotton producers », *J. Agric. Resour. Econ.*, vol. 40, n° 2, p. 325-345, 2015.

[13] J. M. D'Antoni, A. K. Mishra, et H. Joo, « Farmers' perception of precision technology: The case of autosteer adoption by cotton farmers », *Comput. Electron. Agric.*, vol. 87, p. 121-128, 2012, doi: 10.1016/j.compag.2012.05.017.

[14] B. T. Dela Rue et C. R. Eastwood, « Individualised feeding of concentrate supplement in pasture-based dairy systems: Practices and perceptions of New Zealand dairy farmers and their advisors », *Anim. Prod. Sci.*, vol. 57, n° 7, p. 1543-1549, 2017, doi: 10.1071/AN16471.

[15] P. Brown, G. Hart, B. Small, et O. M. de Oca Munguia, « Agents for diffusion of agricultural innovations for environmental outcomes », *Land Use Policy*, vol. 55, p. 318-326, 2016, doi: 10.1016/j.landusepol.2016.04.017.

[16] T. Zhang, Y. Yang, J. Ni, et D. Xie, « Adoption behavior of cleaner production techniques to control agricultural non-point source pollution: A case study in the Three Gorges Reservoir Area », *J. Clean. Prod.*, vol. 223, p. 897-906, juin 2019, doi: 10.1016/j.jclepro.2019.03.194.

[17] J. C. Walton *et al.*, « Grid soil sampling adoption and abandonment in cotton production », *Precis. Agric.*, vol. 11, n° 2, p. 135-147, 2010, doi: 10.1007/s11119-009-9144-y.

[18] G. Danso-Abbeam, G. Dagunga, et D. S. Ehiakpor, « Adoption of Zai technology for soil fertility management: evidence from Upper East region, Ghana », *J. Econ. Struct.*, vol. 8, n° 1, 2019, doi: 10.1186/s40008-019-0163-1.

[19] R. Welsh, S. Grimberg, G. W. Gillespie, et M. Swindal, « Technoscience, anaerobic digester technology and the dairy industry: Factors influencing north country new york dairy farmer views on alternative energy technology », *Renew. Agric. Food Syst.*, vol. 25, n° 2, p. 170-180, 2010, doi: 10.1017/S174217051000013X.

[20] W. Séogo et P. Zahonogo, « Land tenure system innovation and agricultural technology adoption in Burkina Faso: Comparing empirical evidence to the worsening situation of both rural people vulnerability and vulnerable groups' access to land », *Afr. J. Sci. Technol. Innov. Dev.*, vol. 11, n° 7, p. 833-842, 2019, doi: 10.1080/20421338.2019.1587257.

[21] N. Adnan, S. M. Nordin, et Z. bin Abu Bakar, « Understanding and facilitating sustainable agricultural practice: A comprehensive analysis of adoption behaviour among Malaysian paddy farmers », *Land Use Policy*, vol. 68, p. 372-382, nov. 2017, doi: 10.1016/j.landusepol.2017.07.046.

[22] F. Mengistu et E. Assefa, « Farmers' decision to adopt watershed management practices in Gibe basin, southwest Ethiopia », *Int. Soil Water Conserv. Res.*, vol. 7, n° 4, p. 376-387, 2019, doi: 10.1016/j.iswcr.2019.08.006.

[23] G. M. Kaarthikeyan et A. Suresh, « A study on understanding the adoption of water saving technology: A case study of drip irrigation », *Int. J. Recent Technol. Eng.*, vol. 7, n° 6, p. 1123-1130, 2019.

[24] S. C. Chang et C.-H. Tsai, « The adoption of new technology by the farmers in Taiwan », *Appl. Econ.*, vol. 47, n° 36, p. 3817-3824, 2015, doi: 10.1080/00036846.2015.1019035.

[25] M. Keskin et Y. E. Sekerli, « Awareness and adoption of precision agriculture in the Cukurova region of Turkey », *Agron. Res.*, vol. 14, n° 4, p. 1307-1320, 2016.

[26] A. R. Khanal, A. K. Mishra, D. M. Lambert, et K. K. Paudel, « Modeling post adoption decision in precision agriculture: A Bayesian approach », *Comput. Electron. Agric.*, vol. 162, p. 466-474, 2019, doi: 10.1016/j.compag.2019.04.025.

[27] B. A. Aubert, A. Schroeder, et J. Grimaudo, « IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology », *Decis. Support Syst.*, vol. 54, n° 1, p. 510-520, déc. 2012, doi: 10.1016/j.dss.2012.07.002.

[28] P. Roussel et F. Wacheux, *Management des ressources humaines. Méthodes de recherche en sciences humaines et sociales*. Louvain-la-Neuve: De Boeck Supérieur, 2005.

[29] T. Amemiya, « Qualitative Response Models: A Survey », *J. Econ. Lit.*, vol. 19, n° 4, p. 1483-1536, 1981.

[30] D. McFadden, « The Revealed Preferences of a Government Bureaucracy: Empirical Evidence », *Bell J. Econ.*, vol. 7, n° 1, p. 55-72, 1976, doi: 10.2307/3003190.

[31] G. Bucci, D. Bentivoglio, et A. Finco, « Factors affecting ict adoption in agriculture: A case study in italy », *Qual. - Access Success*, vol. 20, n° S2, p. 122-129, 2019.

[32] A. Knierim, M. Kernecker, K. Erdle, T. Kraus, F. Borges, et A. Wurbs, « Smart farming technology innovations – Insights and reflections from the German Smart-AKIS hub », *NJAS - Wagening. J. Life Sci.*, vol. 90-91, 2019, doi: 10.1016/j.njas.2019.100314.