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Farmers' Perception of Soil and Water Conservation Practices and Profit Analysis Using PLS-SEM Model (Case of Oued Rmel Watershed—Tunisia)

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Abstract

The current study investigates farmers' perception and analyzes the benefits of soil and water conservation techniques (SWC) in Oued Rmel watershed (Tunisia), where resource degradation is worsening. Despite the SWC measures put in place by the State, their adoption remains limited. The objective is to understand the efficiency of SWC installations from a human and economic point of view. The survey took place in Oued Rmel basin. The analysis combined descriptive statistics, assessment of the perception of SWC strategies via binary logistic regression, and calculation of gross margin per hectare using the PLS-SEM method. The results revealed that the majority of farmers had a primary level of education and farmed small plots. Crop diversification and the integration of olive trees were common, but land fragmentation was a problem. Only 28% had a favorable opinion of SWC facilities, influenced by land ownership and farm size. PLS-SEM model found that erosion control devices, education level, and agricultural area predicted gross margin per hectare. SWC initiatives have helped to curb erosion, but their socio-economic impact depends on the type of land, agricultural area and production systems. Farmers' perception is linked to land ownership, and gross margin is influenced by agricultural area and production systems.

Keywords: land degradation; farmers' perception; R model; PLS method; Tunisia



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1. Introduction

The problem of degradation of natural resources (water, soil, and vegetation) is constantly growing and attracting the attention of researchers and specialists who are likely to curb this serious scourge (Melalih, 2012) [1]. Land degradation takes many forms under the effect of natural factors (water erosion, wind erosion, drought, aridity, salinization of agricultural land, loss of fertility, impacts of climate change) and anthropogenic factors (clearing of plant cover, urbanization, cultivation techniques unsuitable for topography and soil structure, etc.).

In Tunisia, natural resources (soil, vegetation, water) are in a critical situation due to their excessive exploitation and abusive use, which has led to their degradation at a

level which threatens their sustainability if measures are not taken in the short term and if far-reaching reforms targeting their management are not considered in the medium and long term (Franzel et al., 2014) [2].

Tunisia faces a severe and ongoing crisis of agricultural land degradation and desertification, which poses a significant threat to its food security and rural livelihoods. While official estimates from 2010 suggested annual losses of over 20,000 hectares, more recent studies indicate the persistent and complex nature of the problem. This environmental challenge, driven by climate change, unsustainable farming practices, and socio-economic pressures, has necessitated robust government intervention and the development of long-term soil and water conservation (SWC) strategies.

The degradation of agricultural land in Tunisia is a critical issue that continues to be a significant obstacle to sustainable development. A 2023 study (Cherif et al. 2023) [3] found that almost 6.3% of Tunisia's total land area was degraded between 2016 and 2020. This degradation is a result of several interconnected factors:

- Tunisia is highly vulnerable to climate change, experiencing rising temperatures and increasingly erratic rainfall patterns. A CRDA 2024 [4] report highlighted that the country has already reached the threshold of water scarcity, with overexploitation of groundwater and declining water stocks.
- A study on agricultural land fragmentation in Tunisia, published by Mekki et al. 2018 [5], discusses how small and fragmented landholdings, often resulting from inheritance systems, can hinder the adoption of modern technology and sustainable practices. A 2024 study on soil governance in Tunisia also finds that current institutional frameworks are often "disabling" and do not effectively support soil protection and agroecological transformations.
- The phenomenon of suburbanization and illegal construction on agricultural land is a documented driver of land loss. A 2024 report [4] on land governance reveals that land fragmentation resulting from building construction is a significant issue, particularly in semi-arid regions.

Recognizing the gravity of the situation, the Tunisian government has implemented national SWC strategies since the early 1990s. These strategies are a cornerstone of the country's efforts to combat desertification and ensure agricultural resilience. Key initiatives include the following:

- **Physical and Biological Measures:** The government has heavily promoted mechanical SWC structures such as terraces and contour benches, which are designed to reduce runoff and increase water infiltration, particularly in regions with intense but infrequent rainfall. Biological measures, such as planting windbreaks and agroforestry systems, have also been encouraged to protect against wind erosion and improve soil health.
- **Policy and Institutional Frameworks:** Tunisia has developed a comprehensive legal framework to protect agricultural lands, including the 1983 Agricultural Land Protection Law. Institutionally, the government, through bodies like the General Directorate of Agricultural Land Use and Conservation (DGACTA), has worked to implement these policies and support farmers in adopting SWC techniques.
- **Recent and Ongoing Initiatives:** Recent efforts have focused on promoting agroecological practices as a more holistic solution. The Food and Agriculture Organisation (FAO) and other international partners are supporting projects in Tunisia to promote practices such as planting drought-resistant crops (e.g., carob trees) and adopting agroforestry systems, which help stabilize degraded land and build climate resilience.

Indeed, these water and soil conservation (SWC) facilities aim to improve agricultural production, combat drought and desertification and cope with climate change to protect and improve the socio-economic level of local populations (Laajili-Ghezal, 2018) [6].

Farmers' decisions regarding the adoption of soil and water conservation (SWC) techniques are crucial for sustainable agriculture in Tunisia, a country highly vulnerable to land degradation, desertification, and water scarcity. While the Tunisian government has heavily invested in SWC programs, the adoption rates of these practices by farmers remain a persistent challenge. A purely economic analysis often falls short of explaining why farmers, particularly smallholders, may be reluctant to adopt practices that offer long-term environmental and economic benefits. This highlights the need to understand the complex interplay between farmers' perceptions, including their attitudes, beliefs, and knowledge, and their subsequent impact on farm profitability (Souissi et al., 2024) [7].

Tunisia's agricultural sector is a cornerstone of its economy; however, it faces immense pressure from climate change, characterized by frequent droughts and erratic rainfall. These conditions, combined with intensive agricultural practices, have led to severe soil erosion and the overexploitation of water resources. To combat this, the government and various international initiatives have promoted a range of SWC technologies, from mechanical benches and terraces to no-till farming and localized irrigation (Gharbi et al., 2025) [8].

Despite these efforts, the adoption of many SWC practices is often partial and uneven. Recent studies in Tunisia show that while farmers are aware of the importance of SWC for maintaining productivity, their adoption decisions are influenced by a host of factors beyond pure cost-benefit analysis. This suggests that a farmer's subjective understanding of the risks, benefits, and practicality of a technique—their perception—is a powerful driver of their behavior. For example, a farmer's perception of the profitability of a new irrigation system is as important as the actual return on investment. Recent research in Tunisia has begun to explore farmers' perceptions of sustainability and the transition to agroecological practices. A 2024 study by Souissi et al. [7] investigated the drivers and barriers of agroecological transformation, highlighting the importance of farmers' beliefs and experiences in shaping their decisions. Mgaba (2000) [9] found that ranking soil erosion as the priority problem in agricultural production, participation in labor-sharing groups and having off-farm income influence the willingness and ability to use improved soil conservation technologies and the level of soil conservation efforts. Mgaba (2000) [9] estimated logit models to analyze the perception of the erosion problem and the adoption of improved conservation measures, employing a Poisson regression model of effort devoted to conservation.

Similarly, other research has focused on factors influencing the acceptance of specific SWC techniques, such as conservation agriculture, using econometric models to identify key variables like education level and land tenure. These studies lay the groundwork but often do not fully integrate a farmer's perception as a latent variable that directly influences profitability. This is the gap our research aims to fill. By using a PLS-SEM model, we can go beyond simple correlations to develop a predictive model that shows how a farmer's positive perceptions of the economic and environmental benefits of SWC practices directly contribute to higher adoption rates and, consequently, improved farm profitability. This study offers a more comprehensive perspective, which is crucial for developing effective and sustainable agricultural strategies tailored to the specific context of Tunisia's semi-arid regions.

Similarly, in a previous theoretical framework linking perception to adoption and profitability, Rosillo-Magno et al. (2026) [10] states that a robust and sustainable agricultural framework relies on the adoption of soil conservation for profitability by combining the Theory of Planned Behavior (TPB) and Prospect Theory. This framework posits that farmers'

perceptions of risks and benefits determine their behavioral intention, while the perceived economic cost/benefit ratio (profitability) acts as a mediator, transforming this intention into the actual adoption of sustainable practices.

The components of the theoretical framework are as follows:

Perception (Antecedents): Farmers' awareness of soil degradation and the perceived effectiveness of conservation practices determine their willingness to change.

Adoption (Behavior Change): Guided by the TPB, this step involves attitudes, social norms, and a sense of control, strongly influenced by education and technical support.

Profitability (Outcome and Determining Factor): This is a psychological process of comparing expected costs and revenues, where improved soil fertility boosts productivity and encourages long-term adoption.

This goes along with linking mechanisms such as the following:

Cost–Benefit Sensitivity: Smallholder farmers need clear and tangible financial benefits to justify the adoption costs.

Technology Adoption Model (TAM): Ease of use and perceived usefulness drive the adoption of a conservation technology.

Sustainability Loop: Proper adoption of soil and water conservation (SWC) practices improves productivity and increases profitability, which reinforces positive perceptions and encourages long-term sustainable use.

Accordingly, our research focuses on a dual-pronged investigation into the effectiveness of soil and water conservation (SWC) installations in the Oued Rmel watershed. Our primary goal is to provide a comprehensive understanding of these conservation efforts from both human and economic perspectives. The first objective of this study is to explore and analyze farmers' perceptions of SWC installations. We aim to move beyond a purely technical assessment of these structures to understand how the local farming population views them. The second objective is to quantify the socio-economic effects of SWC amenities on the population of the Oued Rmel watershed. This objective is multifaceted and will be achieved via two main stages: (1) **Gross Margin Analysis:** We will begin by calculating the gross margins for a representative sample of farmers within the watershed. This will provide a baseline economic measure to determine the profitability of their farming activities. By comparing gross margins between farmers who have adopted SWC practices and those who have not, we can begin to isolate the direct economic effects of these interventions. (2) **Variable Detection and Analysis:** The second stage involves using statistical analysis to detect the key variables that affect farmers' profit. We will go beyond a simple comparison of gross margins to identify a range of factors that influence profitability.

2. Materials and Methods

2.1. Study Area

The study area is the Oued Rmel watershed located in the northeast of the Zaghuan delegation, Zaghuan governorate (Figure 1). The latter is located in northern Tunisia and is characterized by a semi-arid climate. A large area of the governorate is affected by erosion, covering approximately 149,000 hectares, or about 53%.

The Oued Rmel watershed covers an area of 675 km² with a perimeter of 131.7 km. The Oued Rmel watershed is located in the northeast of Tunisia, primarily in the governorate of Zaghuan, with a small area belonging to the governorates of Nabeul and Ben Arous. The Oued Rmel basin is located between 36°15' and 36°35' of north latitude and 10°05' and 10°25' of east longitude. The study region is primarily characterized by the dominance of rangelands and agricultural activities, primarily based on cereal cultivation and arboriculture (Jarray, 2024) [11].

SWC amenities in the Zaghouan governorate have been carried out within three national strategies. The first SWC strategy, implemented between 1990 and 2001, reduced the area of eroded soil from 3.5 million hectares to 3 million hectares, resulting in the protection of 500,000 hectares. In 1990, the objective was to develop 600,000 ha by using conventional SWC techniques and 400,000 ha by using gentle SWC techniques intended for cereal cultivation, to build 1000 hill lakes and to carry out 4000 works for spreading flood water; the cost of this strategy was estimated at the time to be 557 million Tunisian dinars (Achouri, 1995) [12]. The second strategy (2002–2011) comprised the following operations: the development of slopes (28,000 ha) and maintenance and safeguarding: SWC structures (28,000 ha), the development of cereal plots (10,000 ha), hill lakes (70 units), spreading and recharge works (100 units), and the correction of ravine lands (25 units) (SWC Administration of Zaghouan, 2012) [13]. The third SWC strategy (2011–2020) is based on the sustainable management of natural resources with a view to developing rural areas, with the following objectives: physical conservation of soils in areas of agronomic potential to maintain soil fertility, fighting against gully on the catchments of large dams, agricultural and pastoral development of SWC facilities, increasing water storage in the soil (green water and/or groundwater), the development of common know-how, and the establishment of good territorial governance. The new 2011–2020 strategy rests on the sustainable management of natural resources for the development of rural areas (SWC Administration of Zaghouan, 2019) [14].

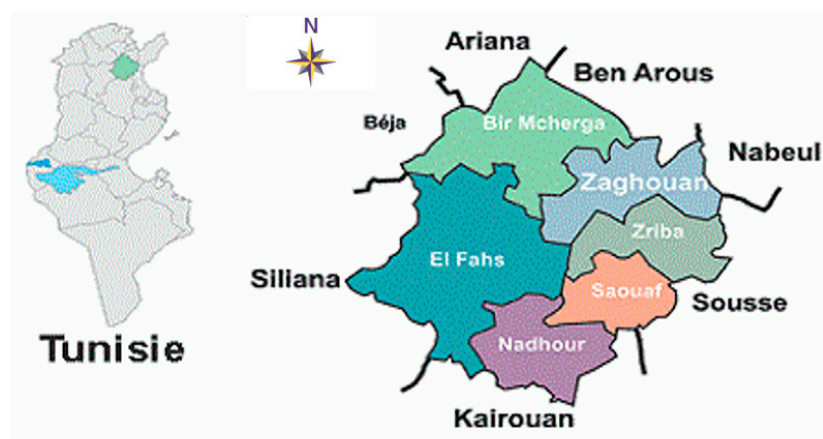


Figure 1. Location of Zaghouan governorate in Tunisia.

In the Oued Rmel region, water and soil conservation was a priority to counter erosion. Farmers had more immediate needs (increased production and income). In fact, in order to introduce SWC actions at the plot level, the district responsible for SWC—being part of the regional agricultural development commission of Zaghouan (CRDA)—was supported by an approach oriented towards the identification and analysis of the problems and needs of the operation and worked out the arrangements according to social conditions. The SWC developments were based on the participative approach, that is to say, the involvement of the population in the choice and implementation of conservation and development actions for agricultural land. Only large areas of land have been developed by SWC works. The SWC Administration has succeeded in (1) developing several SWC amenities (mechanical and manual benches, individual basins, revegetation of ravines, gabion structures and consolidation of the benches), (2) developing several forest plantations, (3) the mobilization of water (construction of the hill lake), (4) the diversification of crops and (5) the development of public awareness of the importance of installing SWC facilities (SWC Zaghouan, 2000) [15].

Figure 2 illustrates the main SWC developments carried out at the level of the watershed studied: gabion structures, benches, consolidation with plantations (Acacia, etc.), and the hill lake.

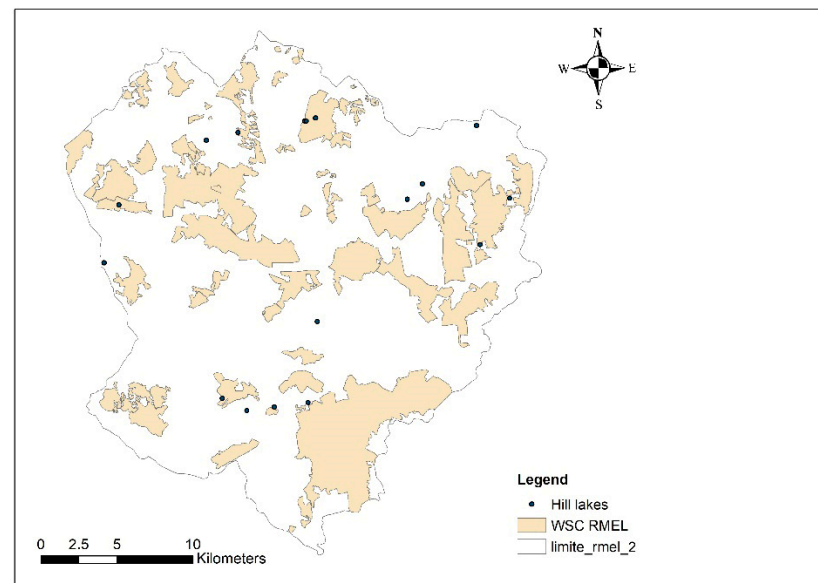


Figure 2. Map of SWC installations on BV in 'raster' format for given resolution.

Figure 3 shows the distribution of land use in the study area. The land is mainly covered by cereals (wheat and barley) and arboriculture (the olive tree). A large part of the area is covered by forests, garrigues, and treeless routes.

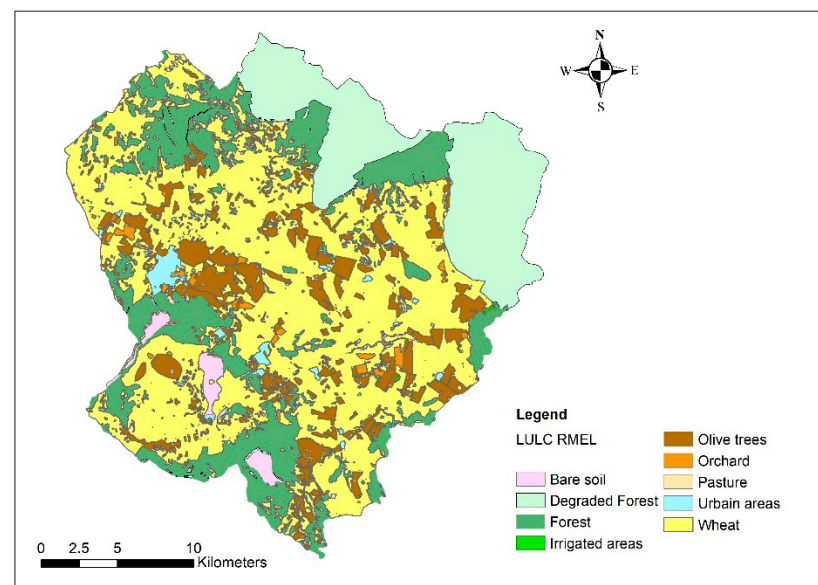


Figure 3. Land cover map in 'raster' format for given resolution.

The area of the Oued Rmel watershed is 367 ha. The average annual temperature is 18.8 °C. The temperature reaches its maximum in August, with an average of around 29 °C, and its minimum in February, with an average of 11 °C. The rainiest month is January, with a rainfall of 93.9 mm, while July has the lowest rainfall, with 0.9 mm.

2.2. Methods of Analysis

2.2.1. Field Survey

Prior to the main data collection phase, preliminary field reconnaissance was conducted to gain a comprehensive understanding of the study area's agricultural landscape and socio-economic context. Based on these initial observations, a structured questionnaire was developed to capture key agricultural and socio-economic variables. The questionnaire was designed to gather information on various aspects, including but not limited to farming practices, crop types, land tenure systems, household demographics, and income sources.

To ensure the instrument's validity and clarity, the questionnaire was pilot-tested with a small, representative group of farmers not included in the final sample. The feedback from this pilot phase was used to refine and finalize the questionnaire.

The study population consisted of all 63 farmers operating within the designated study area. A census approach was adopted, and all members of this population were interviewed to achieve a complete and exhaustive dataset. This comprehensive sampling strategy ensures that the findings are representative of the entire farming community in the region.

Accordingly, we calculated Cronbach's alpha to measure the internal consistency (reliability) of the questionnaire, indicating how closely related a set of items are. With 16 questions (number of items), a sum of item variances of 10, and a total variance of 40, Cronbach's alpha coefficient is 0.8. This result indicates excellent internal consistency, confirming that the items homogeneously measure the same psychometric construct.

The calculation is as follows:

1. Correction factor: $16/(16 - 1) = 16/15 = 1.0667$.
2. Variance ratio: $1 - (10/40) = 1 - 0.25 = 0.75$.

As a result: Cronbach's alpha coefficient = $1.0667 \times 0.75 = 0.8$.

A coefficient of 0.8 demonstrates the high reliability and good internal consistency of the measurement instrument, suggesting that the questions homogeneously measure the same psychometric construct.

2.2.2. Descriptive Analysis of the Variables Analyzed

To effectively characterize the surveyed farms and farmers, a comprehensive descriptive analysis was conducted; for quantitative variables such as the useful agricultural area (SAU), gross margin per hectare (MB), farmer age, number of crops (NbCrops), number of tillage operations (NbTillage), and number of plots (NbPlots), a suite of statistical measures were calculated. These included the minimum and maximum values, the median, the mean, and the standard deviation.

Furthermore, the linear relationships between pairs of quantitative variables were examined using Pearson's correlation coefficient. The statistical significance of these correlations was also determined. For qualitative variables and quantitative variables that were transformed into classes, a categorical analysis was performed by calculating the percentages for each category.

To address the issue of skewed data distributions, specifically for the UAA and GM variables, a log10 transformation was applied. This approach helps to normalize the data, which is essential for meeting the assumptions of parametric statistical tests and ensuring the reliability of the analysis. All statistical computations and analyses were performed using the R statistical software environment (R-4.6.0 for Windows).

2.2.3. Farmers' Perception of SWC Strategy

To investigate the factors influencing farmers' perceptions of soil and water conservation (SWC) facilities, a binary logistic regression model was employed. This statistical

approach is particularly well suited for situations where the dependent variable is dichotomous (has two possible outcomes), as is the case with farmer perception (favorable or unfavorable). It estimates the probability of an outcome occurring based on one or more predictor variables (e.g., farm characteristics, farmer demographics) (Peng et al., 2002; Hosmer & Lemeshow, 2000) [16,17]. The model analyzes the relationship between the independent variables and the logarithm of the odds of a farmer having a favorable perception.

The dependent variable, farmer perception, was coded as a binary variable:

- 1 = Favorable perception of SWC facilities.
- 0 = Unfavorable perception of SWC facilities.

The explanatory variables, which were hypothesized to influence farmer perception, were categorized into four key domains, consistent with similar studies on technology adoption and perception (Sileshi et al., 2019 [18]; Wauters et al., 2010 [19]):

- **Farmland Characteristics:** Variables describing the physical and structural attributes of the farm:
 - **log10(SAU):** The logarithm (base 10) of the useful agricultural area (SAU) to account for data skewness and heteroscedasticity, ensuring a more robust analysis.
 - **Number of plots (NbPlots):** To assess the impact of land fragmentation on a farmer's perception and willingness to invest in SWC.
 - **Land ownership:** A categorical variable indicating the nature of land tenure (inheritance, purchase, and rental), as tenure security is a significant determinant of long-term investment decisions (Sileshi et al., 2019) [18].
- **Farmer Characteristics:** Socio-demographic and human capital factors of farmers:
 - **Age:** A continuous variable to explore how experience and age might influence perception.
 - **Training:** A binary variable indicating whether a farmer has received training from organizations like the Regional Commissariat for Agricultural Development (CRDA) or other sources, as training and exposure to new information are critical for perception formation (Mekonnen et al., 2016) [20].
 - **Level of education:** A categorical variable (illiterate, primary, secondary, higher) to determine the role of formal education in a farmer's awareness and understanding of SWC benefits.
- **Production System:** Variables representing the complexity and diversity of the farming system:
 - **Presence of animal husbandry:** A binary variable to explore the link between mixed farming systems and SWC perception.
 - **Presence of arboriculture:** A binary variable to examine the role of perennial crops in influencing long-term conservation perspectives.
 - **Number of crops (NbCrops):** A continuous variable used as a proxy for crop diversification, which may correlate with a farmer's strategy for mitigating risk and managing resources.
- **Profitability:** The economic performance of the farm, measured by the gross margin per hectare (MB). Similar to SAU, this variable was transformed into **log10(MB)** to normalize the data and mitigate the influence of outliers.

2.2.4. Analysis of the Gross Margin per Hectare

To model the gross margin per hectare (MB), we employed the **Partial Least Squares Structural Equation Modeling (PLS-SEM)** approach. This method is particularly suitable for situations involving complex relationships between observed variables (manifest vari-

ables) and unobserved, or theoretical, constructs (latent variables) (Hair et al., 2017) [21]. Unlike traditional regression methods, PLS-SEM is a component-based approach that prioritizes **predictive accuracy** over causal inference, making it highly effective for exploring and testing theoretical models (Henseler et al., 2016) [22].

So, PLS-SEM is superior to simple regression for analyzing complex models involving latent variables, small sample sizes, and non-normal data (Guenther et al., 2023) [23]. Consequently, PLS-SEM was chosen for this study, as the sample size is limited due to the specific, small population of farmers surveyed in totality in the Oued Rmel watershed.

The PLS-SEM model is composed of two key components:

1. **Measurement Model:** This part of the model defines the relationships between the **manifest variables** (the directly measured indicators) and their corresponding **latent variables** (the theoretical constructs). We distinguished between two types of measurement models:
 - **Formative Measurement Model:** In this model, the manifest variables are considered to *form* or define the latent variable. For example, a farmer's income, number of crops, and land size might collectively "form" a latent variable representing "economic viability."
 - **Reflective Measurement Model:** In this model, the latent variable is considered to *cause* or influence the manifest variables. An example would be a latent variable for "environmental awareness" causing a farmer to use less fertilizer and adopt more conservation practices.
2. **Structural Model:** This component specifies the hypothesized relationships and pathways between the **latent variables** themselves. It allows us to test the theoretical linkages between constructs (e.g., how "economic viability" influences "adoption of new technologies") (Hair et al., 2019) [24].

By using PLS-SEM, we can robustly analyze the factors influencing the gross margin per hectare, taking into account the intricate interplay of various agricultural, socio-economic, and environmental variables.

The structural model used to assess the gross margin is made up of a formative measurement model (formative manifest variables).

The evaluation of a Partial Least Squares Structural Equation Model (PLS-SEM) is a rigorous, two-stage process designed to ensure the reliability and validity of the results (Hair et al., 2017) [21].

The first stage focuses on the **measurement model**, which assesses the quality of the relationships between the manifest variables (indicators) and their corresponding latent variables (constructs). For **formative measurement models**, where the indicators are theorized to *form* the latent variable, a specific set of criteria are applied (Hair et al., 2019) [24]:

- (1) Multicollinearity Assessment: The first step is to check for multicollinearity among the manifest variables using the **Variance Inflation Factor (VIF)**. A high VIF indicates that a manifest variable is highly correlated with other variables in the same block, which can distort the model's estimations. Following standard practice, a VIF value of less than 5.0 is considered acceptable. Variables with VIF values exceeding this threshold should be considered for removal from the model (Hair et al., 2017) [21].
- (2) Indicator Weights and Significance: After addressing multicollinearity, the next step is to examine the **weights** of the manifest variables. These weights represent the contribution of each indicator to its latent variable. The significance of these weights is determined using a non-parametric bootstrapping procedure. Indicators with a significant weight ($p < 0.05$) are typically retained.
- (3) Indicator Loadings: While the weights are the primary metric for formative models, it is also helpful to consider the **loadings** (saturation coefficients). For a robust

formative model, researchers often look for loadings with an absolute value greater than 0.50 or those that are statistically significant, providing additional evidence of the indicator's relevance (Ringle et al., 2015) [25]. This dual assessment helps to ensure that the indicators are not only significant contributors to the construct but also have a meaningful relationship with it.

The second stage of the evaluation process, the structural model evaluation, examines the relationships between the latent variables themselves. This step, which follows the successful evaluation of the measurement model, involves assessing the predictive power and significance of the path coefficients (the hypothesized relationships between the latent variables).

Regarding the structural model, guidelines for assessing f^2 are as follows: values of 0.02, 0.15, and 0.35, respectively, represent small, medium, and significant effects (Cohen, 1988) [26] of the exogenous latent variable. Effect size values of less than 0.02 indicate that there is no effect (Ringle et al., 2015) [25].

The second stage of PLS-SEM evaluation involves assessing the structural model, which focuses on the hypothesized relationships between the latent variables. A critical aspect of this evaluation is determining the effect size (f^2) of the exogenous latent variables. Effect size measures the change in the R^2 of an endogenous latent variable when a specific exogenous latent variable is omitted from the model (Hair et al., 2017) [21]. A larger f^2 value indicates a greater impact of the exogenous variable on the endogenous variable. Based on Cohen's (1988) [26] widely adopted guidelines, the f^2 values are interpreted as follows: small effect: $f^2 = 0.02$; medium effect: $f^2 = 0.15$; large effect: $f^2 = 0.35$. If the f^2 value is less than 0.02, it suggests that the effect of the exogenous latent variable on the endogenous variable is negligible or non-existent (Hair et al., 2019; Ringle et al., 2015) [24,25]. This assessment helps researchers to determine the substantive significance of the relationships in their model, complementing the statistical significance provided by the path coefficients.

3. Results

3.1. Results of the Descriptive Analysis of the Variables

The surveyed farmers exhibited a wide age range, spanning from 25 to 84 years, with a mean age of 53 years. This demographic profile suggests a farming community with significant experience and maturity. A more detailed age distribution reveals that a substantial portion (57%) of the farmers are between 40 and 60 years old. Additionally, 36% of the population is aged over 60, while a small minority (7%) is under 40.

The low representation of younger farmers (under 40 years old) can be attributed to the ongoing phenomenon of rural-to-urban migration. This trend is particularly pronounced in regions neighboring the capital (such as our study site), where younger generations are increasingly opting for non-agricultural jobs over agricultural work. This shift is driven by several socio-economic factors, including the perceived low profitability of agricultural production, limited income opportunities in the sector, and a generational change in aspirations and career goals. These younger individuals seek better employment prospects and improved living conditions that extend beyond traditional farming (Gafsi et al., 2021; Gafsi, 2018) [27,28].

This demographic pattern highlights a critical challenge for the long-term sustainability of agriculture in the region, as it indicates a potential shortage of new farmers to replace the ageing workforce.

The educational attainment of the surveyed farmers demonstrates a relatively high level of literacy and formal schooling. The majority of the farmers (45%) have completed primary education, with a significant portion (29%) having pursued secondary education. A

smaller percentage (19%) are illiterate, and a minority (7%) have attained higher education. This distribution suggests that the farming community is largely educated, which could be a contributing factor to their awareness and perception of environmental issues, such as soil erosion. This relationship will be further explored in the subsequent analysis.

The landholding structure in the study area is characterized by a predominance of small-scale farms. The majority of the surveyed farmers (59%) manage a Useful Agricultural Area (UAA) of less than 5 hectares. This is followed by farms with an area between 5 and 10 hectares (17%). Larger farms are less common, with 12% of farmers owning land between 30 and 70 hectares and only 10% having an area between 10 and 30 hectares. Farms exceeding 70 hectares are rare, accounting for only 2% of the sample. These data confirm that the agricultural landscape of the Oued Rmel region is primarily composed of small farmlands, a common characteristic in many developing agricultural economies (Gafsi et al., 2021) [27].

To analyze the influence of cropping practices on gross margin and farmer perception, a diverse range of crops were systematically grouped into five distinct categories, designed to capture the key variations in land use within the study area. The first category, Monoculture, includes farms cultivating a single crop type, such as fodder (barley, oats), legumes (peas, chickpeas), or vegetables (lettuce). The second, Mixed Cultivation, represents farms that use crop rotation or intercropping to combine different crop types, typically including cereals (such as durum wheat and soft wheat), fodder, and/or legumes. The third group is Olive Trees, consisting of farms dedicated exclusively to this significant perennial crop. The final two categories combine olive cultivation with other practices: Olive Trees + Monoculture, which integrates olive trees with a single annual crop, and Olive Trees + Mixed Cultivation, which combines olives with a more diversified mixed-cropping system. This classification provides a robust framework for a comparative analysis of different farming strategies, offering a more nuanced understanding of their economic and perceptual outcomes rather than a simple crop-by-crop approach (Sileshi et al., 2019; Wauters et al., 2010) [18,19].

The number of crops cultivated by farmers in the study area ranged from one to five, with a dominant trend toward diversification and the integration of olive trees. The majority of farmers (88%) cultivated olive orchards, often in combination with other crops. This widespread adoption of olive cultivation can be primarily attributed to soil and water conservation (SWC) strategies, as planting olive trees provides a natural method of land consolidation and erosion control. The perennial root systems of olive trees help stabilize the soil, particularly on slopes, making them a key component of sustainable land management in the region (Gafsi et al., 2021) [27]. The success of these olive plantations is also a result of strong governmental support. The Tunisian State, through the SWC Administration, has actively encouraged olive tree planting by distributing seedlings and providing technical oversight for orchard development. This partnership between farmers and the state has been crucial in promoting the adoption of these long-term conservation measures.

Despite the prevalence of olive orchards, a minority of farmers (12%) continue to cultivate only annual crops. This is often linked to the economic necessity of farmers with small landholdings. For these farmers, the immediate and regular income provided by annual crops is essential for meeting their household needs, as opposed to the long-term investment and delayed returns associated with olive cultivation (Gafsi, 2018) [28]. This dual cropping strategy reflects the complex interplay between environmental goals, governmental policies, and the immediate economic pressures faced by small-scale farmers.

The agricultural landscape of the Oued Rmel region is significantly impacted by land fragmentation, a phenomenon in which a single farm is divided into multiple, non-contiguous plots. The number of plots per farmer varied between 1 and 6, with an average of 1.9, indicating that most farmers manage their land across multiple parcels. This fragmen-

tation is strongly linked to the dominant land tenure system; the survey revealed that 74% of farmers inherited their land, with only 19% purchasing it and 7% renting. Inheritance laws, often rooted in traditional succession practices in Tunisia, have historically led to the division of land among heirs, thereby exacerbating land fragmentation over generations (Gafsi et al., 2021; World Bank, 2023) [27,29]. A detailed examination of inherited holdings reveals that 39% of these farmers manage between two and six plots.

This high degree of land fragmentation poses a significant barrier to the effective implementation of soil and water conservation (SWC) measures. The Commissariat Régional au Développement Agricole (CRDA), a key governmental body responsible for agricultural development, often requires a minimum land area for the installation of SWC facilities. Small, scattered plots are often deemed unsuitable for specific SWC techniques, as the logistical and financial costs become prohibitive. This policy, combined with the structural issues of land tenure, creates a problematic environment for farmers to adopt essential conservation practices, thereby jeopardizing agricultural sustainability in the region (FAO, 2021) [30]. The challenge of land fragmentation is a critical issue that policy-makers and agricultural development agencies must address to promote widespread adoption of SWC techniques.

Livestock farming is a key component of the agricultural system in the study area, with a substantial portion of farmers (67%) engaging in animal husbandry. This is primarily facilitated by the availability of lake water and the development of rangelands. The predominant livestock types are sheep and goats, with a smaller number of farmers raising dairy cattle. These herds are primarily sustained by grazing on rangelands and forest scrub. Practices such as poultry farming and beekeeping are rare and are mainly for household self-consumption.

Tillage practices in the region demonstrate a growing awareness of soil conservation, as evidenced by the low number of ploughing operations, which range from one to three per year. The majority of farmers (76%) utilize contour ploughing, which aligns their furrows perpendicular to the slope, thereby reducing water runoff and soil erosion. This suggests a strong understanding and consciousness of erosion control techniques.

However, a minority of farmers (24%) continue to plough their land parallel to the slope (against contour lines). These farmers cited concerns that contour ploughing could damage their agricultural machinery. This indicates a gap in their awareness regarding the severe consequences of ploughing against contour lines, which accelerates water runoff and significantly increases the rate of water erosion and soil loss (Sileshi et al., 2019) [18]. The data highlight the need for targeted education and outreach to improve farmer understanding of the long-term benefits of proper tillage techniques for soil health and sustainability.

Before the construction of the SWC and hill lake facilities, farmers only grew wheat and barley. After the installation of these facilities and the lake, the cultures became diversified. In addition to cereal crops, other crops have been introduced, such as arboriculture (olive and almond) and fodder crops like Sulla, oats, and vetch. Therefore, the developments have contributed to the diversification of crops in the Oued Rmel region.

The sustainability of soil and water conservation (SWC) facilities is a critical factor in their long-term effectiveness. Our survey revealed that a substantial portion of the farmers, nearly half (59%), have developed plots with SWC facilities, and of these, 33% are actively maintained. The importance of maintenance cannot be overstated, as it ensures the structural integrity of the facilities against climatic events and animal activities (Ludi et al., 2012) [31].

In the Oued Rmel region, the responsibility for maintaining these facilities falls to the SWC district of the Commissariat Régional au Développement Agricole (CRDA). However, this service is provided only upon the farmer's request. Our field observations and

survey data suggest that the majority of farmers understand the necessity of this upkeep. Conversely, 26% of operators have facilities that are not maintained due to two main factors: a lack of awareness regarding the importance of SWC maintenance or the physical absence of the farmer from the farm (i.e., they live off site). This disconnection between land ownership and on-site presence often leads to the neglect of essential conservation infrastructure, undermining efforts to combat land degradation (Sileshi et al., 2019) [18].

The economic performance of the farms, measured by the gross margin per hectare (GM/ha), showed considerable variation. Values ranged from a minimum of 525.5 TD/ha to a maximum of 5730.8 TD/ha, with a median of 1673.5 TD/ha and an average of 2012.4 TD/ha. A closer look at the distribution of gross margins reveals that most farmers (55%) operate within a moderate range, with a GM/ha between 1000 and 2000 TD/ha. A smaller proportion (22%) achieves a higher profitability, with margins between 2000 and 4000 TD/ha. Only a small minority (10%) of the farms generated a gross margin greater than 4000 TD/ha, indicating that high-profit farming is not widespread in the region. A notable finding is that 14% of the farmers reported a very low GM/ha, which is primarily attributed to low agricultural yields. This suggests that a segment of the farming community is struggling with low productivity, which may be the result of various factors such as soil degradation, limited access to resources, or poor agricultural practices. This finding is consistent with studies that highlight the vulnerability of small-scale farmers to yield fluctuations and their direct impact on farm profitability (World Bank, 2023) [29].

3.2. Relationships Between Variables

The results obtained in Figure 4 help us to analyze the relationships between the variables.

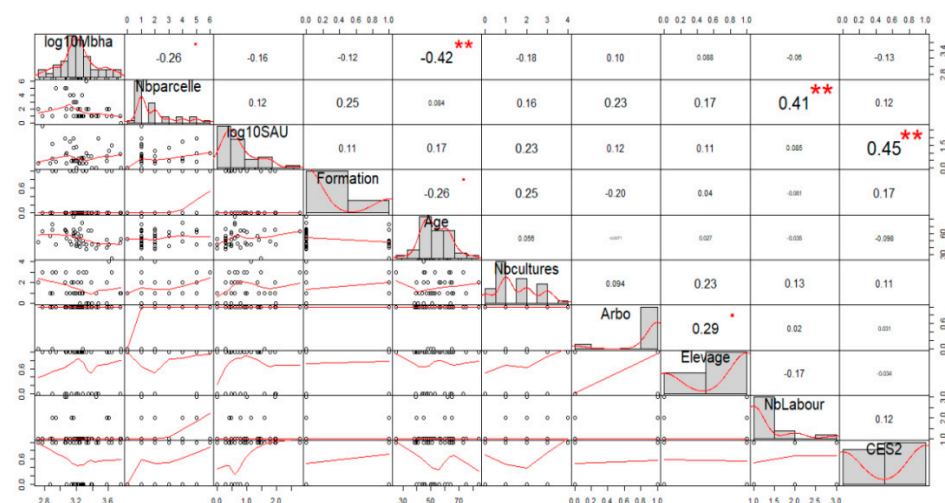


Figure 4. Point cloud representation (with smoothing) and correlations (with degree of significance). Moreover, distribution of variables studied.

The GM (transformed into log10 MB/ha) is significantly negatively correlated with the number of plots (Nbparcelle) and age (Age). Indeed, fragmentation is a handicap for farmers in managing their land as well as possible, reducing their gross margin per hectare. Additionally, it appears that young farmers have a greater interest in managing their land. In addition, given the rural exodus, resulting in a lack of young labor, elderly farmers are forced to do all the work themselves, which limits their earnings. Also, animal husbandry and arboriculture were found to be positively and significantly correlated. Indeed, the by-products of the cultivation of olive trees are used for feeding cattle, such as the twigs, the leaves after pruning of the olive trees, and the residues that result from the crushing of

the olives. Additionally, several farmers cultivate intercropping with rows of olive trees. So, the olive tree is a source of money and also a fodder reserve.

Finally, a positive relationship exists between the UAA and the presence of SWC facilities. In fact, the SWC Administration installs these developments only on large areas of land because they consume a significant amount of space.

3.3. Results of the Perception Analysis of the SWC Facilities

A significant finding from our analysis is that a small proportion of the surveyed farmers, specifically 28%, expressed a favorable view toward the installation of soil and water conservation (SWC) facilities. To understand the factors driving this perception, we conducted a Deviance analysis (ANODEV) on a series of logistic regression models. Each model tested the individual effect of various explanatory variables on farmer perception.

The results of the ANODEV revealed that only two variables had a statistically significant effect on the binary perception variable (favorable vs. not favorable) at a significance level of $p < 0.0005$. These key determinants were land ownership and $\log_{10}(\text{SAU})$ (the logarithm of the Useful Agricultural Area). This finding suggests that a farmer's perception of SWC strategies is not randomly distributed but is significantly influenced by the characteristics of their land tenure and farm size. This finding is consistent with previous research, which has shown that land security and the scale of agricultural operations are strong predictors of a farmer's willingness to invest in and adopt conservation practices (Sileshi et al., 2019; Wauters et al., 2010) [18,19].

The significant effect of landownership underscores the importance of tenure security in long-term investment decisions. In contrast, the effect of farm size highlights the role of economies of scale in the adoption of SWC technologies. The detailed results of the ANODEV are presented in Table 1.

Table 1. Influence of each explanatory variable on farmers' perception of SWC work: Deviance analysis. * $p < 0.0005$.

	DL	Chi2	Pr (>Chi2)	
Land ownership	2	8.3707	0.01522	*
$\log_{10}\text{UAA}$	1	3.9001	0.04828	*
NbPlots	1	0.0301	0.8623	
Livestock	1	0.5202	0.4707	
NbCrops	1	0.6419	0.423	
Arboriculture	1	0.9334	0.334	
LevEducation	3	1.1648	0.7615	
Age	1	0.108	0.7425	
Training	1	0.8236	0.3641	
$\log_{10}\text{GM/ha}$	1	1.323	0.2501	

For the land ownership variable, farmers who bought their land are significantly more in favor of SWC facilities than those who inherited their land; tenant farmers are intermediate and do not differ significantly from the other two categories (Figure 5). The results, therefore, show that farmers who hold their land by purchase have a better perception of SWC work than those who inherited their land. This could be explained by the fact that buying farmers are more interested in agricultural activities, where the choice of the rural world stems from their own will, and the appropriation of the land proves it. Consequently, they are more aware of the environmental problems linked to the land degradation, which prompts them to adopt a favorable view towards these conservation amenities. On the other hand, certain heirs declare that they find themselves forced to be farmers by inheritance and want to escape a life of agricultural work, which turns out to

be increasingly unprofitable and exhausting, by moving towards industrial and service activities in the cities. In addition, the new owners typically buy land that is larger than that of the heirs; this is due to the phenomenon of inheritance and fragmentation. In addition, these heirs do not hold a well-regulated appropriation, which makes them insensitive to degradation scourge. On the other hand, buyers are well aware that they are serving their land, as land ownership is clearly defined.

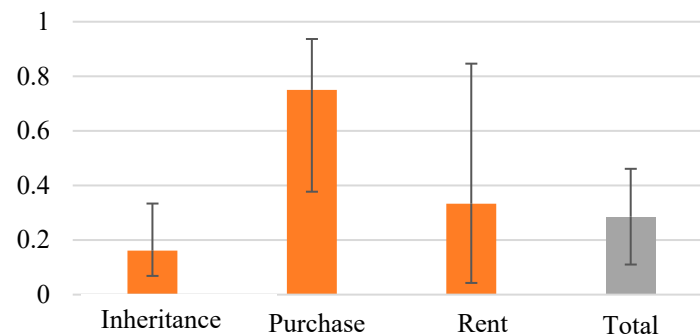


Figure 5. Favorable perception of SWC facilities depending on their land ownership.

Regarding the variable UAA, it appears that the larger it is, the more favorably the farmer perceives SWC strategies. In fact, as already mentioned, only land with large areas can be managed with SWC amenities. Below, we provide the equation of the logistic model, which explains the relationship between the UAA and the farmer's land ownership:

$$\text{logit}(p) = \log(p/(1-p)) = -1.8889 + 1.1324 \times \log_{10} \text{UAA}$$

To further refine the analysis of factors influencing farmer perception, a stepwise logistic regression was performed. This method systematically adds or removes variables from the model based on their statistical significance. The stepwise procedure ultimately retained only one explanatory variable: land ownership. This variable was found to have a significant effect on farmer perception, with a Chi-square probability (p) of 0.01125.

The final logistic model proved to be statistically significant when compared to the null model, as indicated by a Chi-square probability of 0.005297. This result confirms that the model, with land ownership as a predictor, provides a better explanation for the variation in farmer perception than a model with no predictors. Furthermore, a key diagnostic check was performed to assess the model's fit. The Deviance divided by the degrees of freedom (DF) was 0.9879001, which is very close to 1. This value suggests that the model does not suffer from over-dispersion, meaning that it is an appropriate and reliable fit for the data (Ringle et al., 2015) [25]. Finally, the model's predictive power was evaluated using McFadden's Pseudo-R², which yielded a value of 0.2530. While not directly comparable to the R² in a linear regression, this value is considered a good indicator of the model's quality, suggesting that a significant portion of the variance in farmer perception is explained by land ownership (Hair et al., 2017) [21].

3.4. Result of the Analysis of the Gross Margin per Hectare

The multicollinearity between the manifest variables (MVs) of the selected model (Figure 6) was assessed by examining the values of the VIF ("Variance Inflation Factor").

For all variables, the VIF was less than 5, indicating no problem of collinearity between these variables (Table 2).

The analysis of the latent variable model revealed three manifest variables with statistically significant weights, indicating their relative importance in influencing the gross margin per hectare (GM/ha). These variables were as follows: (1) SWC: The presence

or absence of anti-erosion facilities. This suggests a strong link between the adoption of conservation practices and farm profitability. (2) Level of education: A dichotomous variable comparing farmers with secondary or higher education to those who are illiterate or with only primary education. This finding underscores the role of human capital in driving farm economic performance. (3) UAA: The Useful Agricultural Area, which represents the size of the farm. This variable is a key determinant of the scale of operations and, consequently, the potential for higher gross margins.

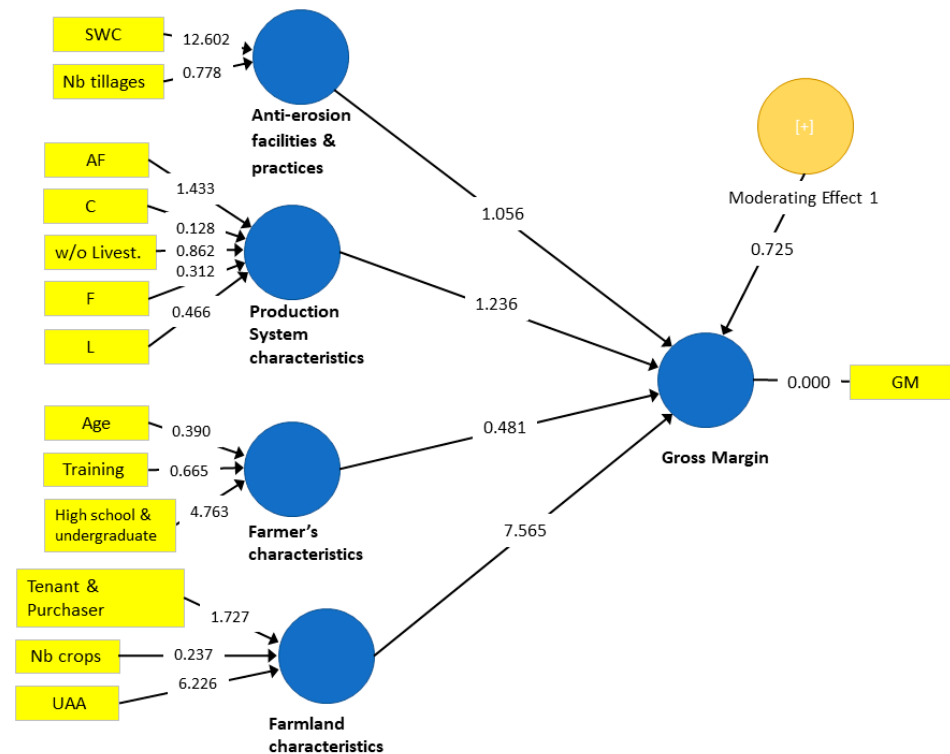


Figure 6. The final model used to predict the gross margin with the values of the *t*-test, allowing the significance of the standardized “path coefficients” to be evaluated.

Table 2. VIF values of the manifest variables.

	VIF
AF: Both arboriculture and fodder crops	1.564
Farmer's age	1.099
C: Cereal crops	1.465
WSC: Soil and water conservation	1.014
Livestock integration: without livestock	1.187
F: Fodder crops	1.715
Farmer training	1.084
L: Leguminous crops	1.351
Tenant and Purchaser: farmer, tenant and purchaser of land	1.249
GM: Gross margin	1.000
NbTillage: number of tillage per land	1.014
NbCrops: number of crops	1.061
UAA: Useful Agricultural Area	1.292
Level of education: High school and undergraduate levels	1.029

These three manifest variables—SWC, education level, and UAA—were found to be significant predictors within the Partial Least Squares Structural Equation Modeling (PLS-SEM) framework, demonstrating their collective importance in explaining the variation in farm profitability. The detailed results of the model, including the weights and their significance, are presented in Table 3.

Table 3. The weight values of the manifest variables (MVs), standard deviation, significance level and confidence interval (CI) at the significance level of 0.05.

		Original Sample (O)	Standard Deviation (STDEV)	<i>p</i> Values	CI 2.5%	CI 97.5%
Anti-erosion facilities and practices	SWC: Soil and water conservation	1.001	0.079	0.000	0.919	1.117
	Nb tillage: Number of tillage per land	−0.223	0.287	0.437	−0.624	0.507
Production system characteristics	AF: Both arboriculture and fodder crops	0.986	0.688	0.152	0.020	1.635
	C: Cereal crops	0.047	0.368	0.898	−0.729	0.729
	F: Fodder crops	0.178	0.572	0.755	−0.963	1.061
	L: Legume crops	−0.278	0.597	0.641	−1.156	0.792
	Livestock integration: without livestock	0.401	0.466	0.389	−0.459	1.048
Farmer's characteristics	Age	0.121	0.310	0.697	−0.517	0.675
	Training	0.191	0.287	0.506	−0.262	0.853
	Level of education: High school and undergraduate levels	1.009	0.212	0.000	0.942	1.193
Farmland characteristics	Tenant and Purchaser: tenant and purchaser of land	0.327	0.189	0.084	0.094	0.769
	NbCrops: Number of cultivated crops	−0.028	0.120	0.813	−0.255	0.192
	UAA	0.820	0.132	0.000	0.367	1.009

The loading values characterize the absolute importance of the manifest variables, taken individually (without considering the other variables), in relation to the gross margin (GM/ha). Those which have a significant absolute importance ($p < 0.05$) or high loading (loading > 0.50) are as follows: (1) the variable AF (integration of fodder crops with arboriculture (olive trees)), (2) F (practice of fodder crops), (3) the variable land ownership (buyer and tenant vs. heir) (Table 4).

The remaining manifest variables had no significant impact on the model, as evidenced by their statistical insignificance. Their weights and loadings both had p -values greater than 0.05, indicating that they do not contribute meaningfully to the latent variable and are not considered strong predictors of the gross margin per hectare.

It should be noted that the weight, which is equivalent to a regression coefficient in a linear model, represents the relative contribution of the manifest variable (items) to the latent variable and, consequently, to the endogenous variable (the MB in our case). We discuss relative importance, but the loading value enables us to assess the absolute importance of a manifest variable in relation to its latent variable and, consequently, the endogenous variable. It actually represents the bivariate correlation with the latent variable (this is a correlation), while ignoring the other overt variables.

Concerning the structural model, analysis of the significance of the standardized coefficients (“path coefficients”) of the PLS-SEM model shows that all the latent variables integrated into the model have positive effects on GM/ha. However, the characteristics of the farm ($p < 0.0001$) have a highly significant effect compared to the other latent variables (construct variables) (Table 5).

Table 4. The saturation values (loadings) of the manifest variables (MVs), standard deviation, prediction and confidence interval (CI) at the significance level of 0.05.

		Original Sample (O)	Standard Deviation (STDEV)	p Values	CI 2.5%	CI 97.5%
Anti-erosion facilities and practices	SWC: Soil and water conservation	0.975	0.065	0.000	0.832	1.000
	NbTillage: Number of tillage per land	−0.107	0.297	0.718	−0.477	0.717
Production system characteristics	AF: Both arboriculture and fodder crops	0.899	0.340	0.008	0.894	0.991
	C: Cereal crops	0.328	0.313	0.295	−0.294	0.824
	F: Fodder crops	0.552	0.370	0.136	−0.214	0.957
	L: Legume crops	0.079	0.363	0.828	−0.600	0.640
	Livestock integration: without livestock	0.053	0.364	0.885	−0.517	0.711
Farmers characteristics	Farmer's age	−0.063	0.353	0.859	−0.750	0.602
	Farmer training	0.092	0.314	0.769	−0.373	0.809
	Level of education: High school and undergraduate levels	0.981	0.214	0.000	0.901	1.000
Farmland characteristics	Tenant & Purchaser: tenant and purchaser of land	0.677	0.109	0.000	0.460	0.875
	NbCrops: Number of cultivated crops	0.108	0.220	0.621	−0.362	0.443
	UAA	0.953	0.033	0.000	0.818	0.995

Table 5. Standardized coefficients (“path coefficients”) of the PLS-SEM model, as well as the standard deviation (SD), pr significance and confidence interval (CI).

	Standardized Coeff.	SD	pr	CI 2.5%	CI 97.5%
Anti-erosion facilities and practices	0.073	0.069	0.291	−0.022	0.238
Farmers characteristics	0.052	0.108	0.631	−0.142	0.296
Farmland characteristics	0.806	0.107	0.000	0.517	0.968
Production system characteristics	0.132	0.107	0.216	0.001	0.477
ModeratingEffect1 → Gross Margin	0.096	0.132	0.469	−0.068	0.415

The R² (adjustment coefficient) of the model is around 0.795. Thus, the fitted model is considered good and consistent (Hair et al., 2019) [24].

The analysis of the structural model, which examines the relationships between latent variables, utilized the effect size (f^2) to determine the substantive impact of exogenous variables on the gross margin per hectare. The results, as detailed in Table 6, indicate varying levels of influence: (1) Farmer Characteristics: The latent variable representing farmer characteristics (e.g., age, education) showed an f^2 value of less than 0.02, indicating no significant effect on the gross margin. This suggests that, within our model, these demographic and human capital factors do not have a strong direct influence on farm profitability. (2) Anti-Erosion Facilities and Practices and Production System Characteristics: Both of these latent variables were found to have f^2 values between 0.02 and 0.15, which, according to Cohen's (1988) [26] guidelines, represents a small effect. This indicates that while these factors do contribute to farm profitability, their impact is limited compared to other variables. (3) Farm Characteristics: The latent variable encompassing farm characteristics (e.g., land size, fragmentation) demonstrated an f^2 value greater than 0.33, signifying a large effect. This finding suggests that the physical and structural attributes of the farm

are the most significant drivers of the gross margin per hectare, underscoring the critical role of land-related factors in determining economic performance.

This analysis highlights that while some factors have a measurable but small impact, the physical characteristics of the farm are the primary determinant of profitability in the study area.

Table 6. Effect size of PLS-SEM model: value, standard deviation, pr significance, and CI.

	Value	SD	pr	CI 2.5%	CI 97.5%
Anti-erosion facilities and practices	0.023	0.060	0.701	−0.226	0.116
Farmers characteristics	0.008	0.105	0.938	−0.303	0.167
Farmland characteristics	2.208	5.364	0.681	0.093	0.093
Production system characteristics	0.076	0.148	0.605	−0.105	0.310
ModeratingEffect1 → Gross Margin	0.035	0.177	0.842	−0.241	0.301

The analysis of the measurement model (Figure 7) provides a detailed understanding of how specific manifest variables influence the latent variables, ultimately leading to the gross margin per hectare (GM/ha).

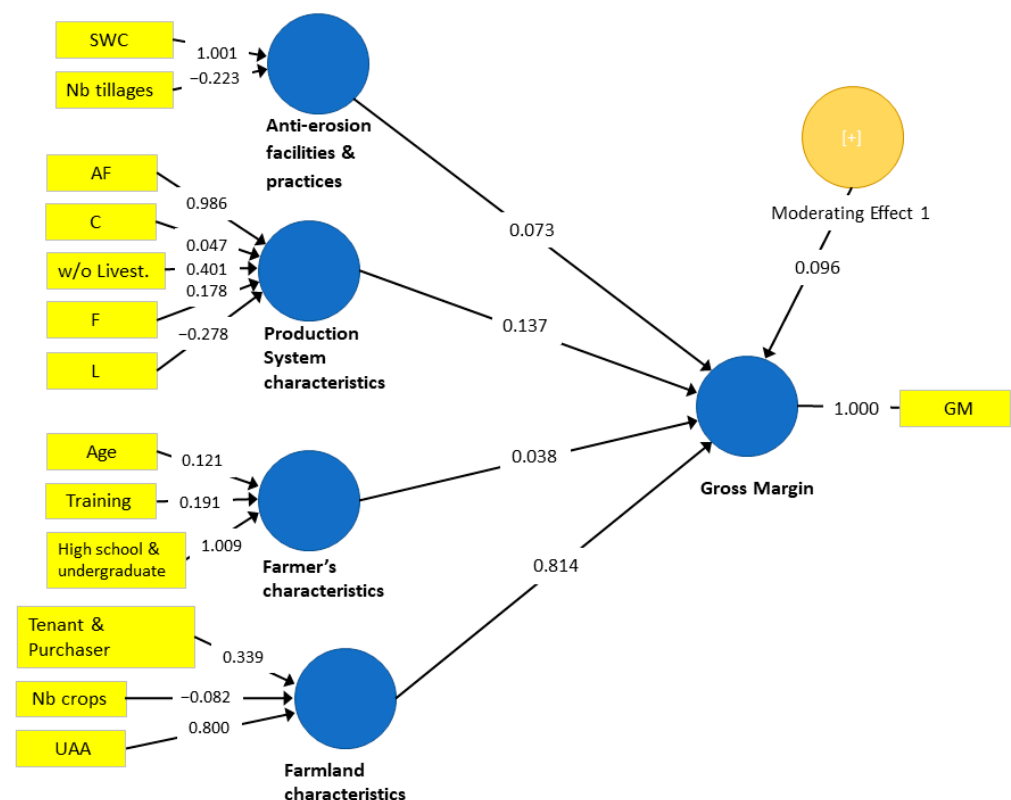


Figure 7. The final model used to predict the gross margin, with the standardized coefficients (“path coefficients”) for the latent variables (in blue), weight (weights) for the manifest variables (in yellow), and R2.

The presence of conservation techniques (SWC) was found to have a significant positive effect on the gross margin. This suggests that anti-erosion measures are effective, likely due to their role in enhancing soil fertility and increasing water infiltration, which in turn boosts crop yield (Sileshi et al., 2019) [18]. Conversely, the number of ploughs had a slightly negative but non-statistically significant effect on GM/ha. This finding, although not statistically significant, suggests that reducing excessive tillage could be a strategy for

increasing profitability, as excessive ploughing can weaken soil structure and accelerate soil erosion.

The integration of arboriculture (AF), particularly with olive and almond trees, alongside other crops, had a positive effect on the gross margin. This suggests that these perennial crops make a significant contribution to farm profitability. However, when integrated with other manifest variables, its overall contribution to the model was not substantial. Meanwhile, cereal and fodder crops showed a positive but not significant effect on GM/ha, likely due to the high cost of seeds, which makes these crops less profitable (Gafsi, 2018) [28].

The analysis of farmer characteristics revealed that the level of education has a significant and positive effect on GM/ha. Farmers with secondary or higher education generally achieve better gross margins than those with primary education or those who are illiterate. However, age and farmer training (from CRDA and NGOs) did not have a significant effect on GM/ha. This could be because the farmers' own field experience and self-learning play a more dominant role in achieving a good gross margin than formal training programs.

The Useful Agricultural Area (UAA) had a significant and positive effect on GM/ha. This relationship can be attributed to economies of scale: larger farms can better absorb fixed costs, which leads to an increase in the gross margin per hectare (World Bank, 2023) [29].

While the latent variable for property ownership did not demonstrate significant relative importance in relation to the gross margin per hectare (GM/ha), its absolute importance was noteworthy. The results showed that farmers who either purchased or leased their land achieved a higher GM/ha compared to those who inherited it.

This discrepancy may be explained by the differing motivations of farmers based on their land acquisition method. Farmers who actively buy or rent their land often show a higher level of commitment and passion for agriculture, as it is a deliberate choice rather than an inherited obligation. These individuals are more likely to invest in efficient management practices to maximize profitability. Conversely, farmers with a history of generating substantial profits may be incentivized to purchase additional land, thereby further increasing their wealth and the scale of their operations.

In contrast, inherited land ownership often presents challenges, such as fragmented plots and unclear legal titles, which can deter long-term investment. Additionally, many heirs may feel a sense of dissatisfaction with the agricultural sector due to its perceived lack of prospects, leading them to be less invested in the success of their farms (Gafsi et al., 2021) [27]. This emotional and financial detachment from the land may contribute to lower gross margins.

4. Discussion

Soil and water conservation developments in the Oued Rmel watershed have helped reduce erosion, but have they improved the socio-economic gain of farmers? To address this issue, farmers' perception of these developments must be studied. This study enabled us to answer this question while identifying the causes and the primary influencing factors.

In fact, the results of this study have revealed different criteria that affect a farmer's approval of installing these SWC facilities on their farm. These criteria, in particular, depend on the characteristics associated with the type of land. Indeed, buyers have a favorable perception of these conservation developments.

As for the gross margin, the criteria linked to exploitation, especially the UAA and to anti-erosion facilities and practices, particularly the installation of SWC structures, turn out to be the criteria most influencing the gross margin per hectare. Then come the production systems, in particular the integration of fodder crops into arboriculture. The characteristics of the farmer have the weakest effect, designated by level of education.

This work opens up new perspectives for future research. For example, we could integrate the farmer's extra-agricultural activity, or even his wife's, into the study of farmers' perceptions of SWC facilities and also into the study of the gross margin. Additionally, are there other overt variables that would better characterize the latent variables identified in our gross margin study? For example, we could include proximity to the lake (in the characteristics of anti-erosion facilities and practices), as well as the type of irrigation system (irrigated or dry) and mechanization (in the characteristics of the production system).

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Informed Consent Statement: Ethical considerations were addressed by obtaining verbal informed consent from all participants, ensuring anonymity, and adhering to research ethics principles. Thus, patient consent was waived.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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References

1. Melalih, A. *Analyse des Techniques de Conservation de L'eau et du sol Dans la Zone Aride cas Bassin Versant d'AIN SEFRA, Mémoire*; Université Abou-bekr Belkaid de Tlemcen: Chetouane, Algeria, 2012; 143p.
2. Franzel, S.; Carsan, S.; Lukuyu, B.; Sinja, J.; Wambugu, C. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Curr. Opin. Environ. Sustain.* **2014**, *6*, 98–103. [CrossRef]
3. Cherif, I.; Kolintziki, E.; Alexandridis, T.K. Monitoring of Land Degradation in Greece and Tunisia Using Trends. Earth with a Focus on Cereal Croplands. *Remote Sens.* **2023**, *15*, 1766. [CrossRef]
4. CRDA. Annual Report. 2024. Available online: <https://www.croda.com/en-gb/investors/annual-report/2024> (accessed on 6 May 2026).
5. Mekki, I.; Bailly, J.S.; Jacob, F.; Chebbi, H.; Ajmi, T.; Blanca YZairi, A.; Biarnès, A. Impact of farmland fragmentation on rainfed crop allocation in Mediterranean landscapes: A case study of the Lebna watershed in Cap Bon, Tunisia. *Land Use Policy* **2018**, *75*, 772–783. [CrossRef]
6. Laajili-Ghezal, L. Study of the Effects of Two Crop Systems and Best Management Practices on Soil and Water Conservation in Tunisian Semi-arid Area. *Univers. J. Agric. Res.* **2018**, *6*, 72–78. [CrossRef]
7. Souissi, A.; Dhehibi, B.; Oumer, A.M.; Mejri, R.; Frija, A.; Zlaoui, M.; Dhraief, M.Z. Linking farmers' perceptions and management decision toward sustainable agroecological transition: Evidence from rural Tunisia. *Front. Nutr.* **2024**, *11*, 1389007. [CrossRef] [PubMed]
8. Gharbi, I.; Aribi, F.; Abdelhafidh, H.; Ferchichi, N.; Lajnef, L.; Toukabri, W.; Jaouad, M. Assessment of the Agroecological Transition of Farms in Central Tunisia Using the TAPE Framework. *Resources* **2025**, *14*, 81. [CrossRef]
9. Mgaba, Z. Household adoption behaviour of improved soil conservation: The case of the North Pare and West Usambara Mountains of Tanzania. *Land Use Policy* **2000**, *17*, 321–336. [CrossRef]

10. Rosillo-Magno, A.P.; Montemayor, M.M.; Bulahan, M.A.; Himang, C.M. Are perceived soil erosion risks sufficient to drive vetiver system technology adoption? Insights based on TAM-PMT integrated framework. *Soil Secur. Sci. Direct* **2026**, *22*, 100227. [CrossRef]
11. Jarray, F. Long-Term Impact of Soil and Water Conservation Measures on Soil Erosion in a Tunisian Semi-Arid Watershed. *J. Land* **2024**, *12*, 1537. [CrossRef]
12. Achouri, M. La Conservation des Eaux et du sol en Tunisie: Bilan et Perspectives. *Cah. Options Mediterr.* **1995**, *9*, 35–47. Available online: <https://om.ciheam.org/ressources/om/pdf/c09/96605578.pdf> (accessed on 6 May 2026).
13. SWC Commissariat Regional de Développement Agricole de Zaghouden, Arrondissement CES. *Variation of the New Strategy in Strategic Directions*; SWC Commissariat Regional de Développement Agricole de Zaghouden, Arrondissement CES: Zaghouden, Tunisia, 2012.
14. SWC Commissariat Regional de Développement Agricole de Zaghouden, Arrondissement CES. *Variation of the New Strategy in Strategic Directions*; SWC Commissariat Regional de Développement Agricole de Zaghouden, Arrondissement CES: Zaghouden, Tunisia, 2019.
15. SWC Commissariat Regional de Développement Agricole de Zaghouden. *Participatory Planning in the Oued Sbahiya Watershed*; FAO/Italy Cooperation Program; SWC Commissariat Regional de Développement Agricole de Zaghouden: Zaghouden, Tunisia, 2000; pp. 8–9.
16. Peng, C.Y.J.; Lee, K.L.; Ingersoll, G.M. An introduction to logistic regression analysis and reporting. *J. Educ. Res.* **2002**, *96*, 3–14. [CrossRef]
17. Hosmer, D.W.; Lemeshow, S. *Applied Logistic Regression*; Wiley: Hoboken, NJ, USA, 2000.
18. Sileshi, M.; Kadigi, R.; Mutabazi, K.; Sieber, S. Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. *Int. Soil Water Conserv. Res.* **2019**, *7*, 354–361. [CrossRef]
19. Wauters, E.; Bielders, C.L.; Poesen, J.; Govers, G.; van Dijk, N. A study of the adoption of soil and water conservation practices in the Seme Watershed, Central Plateau, Burkina Faso. *Appl. Geogr.* **2010**, *30*, 226–235.
20. Mekonnen, H.; Kebede, K.; Hasen, M.; Tegegne, B. Farmer's Perception of Soil and Water Conservation Practices in Eastern Hararghe, Ethiopia. *Zesz. Nauk. SGGW Warszawie-Probl. Rol. Swiat.* **2016**, *16*, 232–239. [CrossRef]
21. Hair, J.F.; Hult, G.T.M.; Ringle, C.M.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modelling (PLS-SEM)*, 2nd ed.; SAGE Publications: Thousand Oaks, CA, USA, 2017.
22. Henseler, J.; Ringle, C.M.; Sarstedt, M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J. Acad. Mark. Sci.* **2016**, *43*, 115–135.
23. Guenther, P.; Guenther, M.; Ringle, C.M.; Zaefarian, G.; Cartwright, S. Industrial Marketing Management. Improving PLS-SEM use for business marketing research. *Ind. Mark. Manag.* **2023**, *111*, 127–142.
24. Hair, J.F.; Risher, J.J.; Sarstedt, M.; Ringle, C.M. When to use and how to report the results of PLS-SEM. *Eur. Bus. Rev.* **2019**, *31*, 2–24. [CrossRef]
25. Ringle, C.M.; Wende, S.; Becker, J.-M. *SmartPLS 3*; SmartPLS GmbH: Boenningstedt, Germany, 2015. Available online: <http://www.smartpls.com> (accessed on 20 October 2018).
26. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 1988.
27. Gafsi, M.; Hassen, S.B.; Sghaier, M. Rural youth migration in Tunisia: Causes, consequences and policy implications. *J. Rural Stud.* **2021**, *85*, 1–10.
28. Gafsi, M. Youth unemployment, rural exodus and agricultural policies in Tunisia. *Agric. Food Econ.* **2018**, *6*, 1–15.
29. World Bank. *Tunisia Land Sector Snapshot*; World Bank: Washington, DC, USA, 2023.
30. Food and Agriculture Organization of the United Nations (FAO). *The State of Food and Agriculture: Making Agrifood Systems More Resilient to Shocks and Stresses*; FAO: Rome, Italy, 2021.
31. Ludi, E.; Jones, H.; Varley, H. The importance of maintenance in successful soil and water conservation projects. *Land Degrad. Dev.* **2012**, *23*, 1–11.

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