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Improving Risk-management Strategies Through Technical and Economic Alternatives in Moroccan Rainfed Agriculture: Target MOTAD Modeling Approach

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Abstract

In the face of growing challenges posed by climate change, enhancing the resilience of the agricultural sector has become a crucial issue to ensure food security and achieve the sustainable development goals. In rainfed areas, agricultural production and the use of natural resources are directly linked to climatic conditions, which explains the multiplicity of adaptation strategies employed by farming households to ensure the resilience of agricultural systems. This research reflects the concerns regarding the strengthening of agricultural resilience in semi-arid regions. The research examines through a Target MOTAD (Minimization of Total Absolute Deviation) model the assessment of different risk level scenarios among farmers in the studied area. The findings reveal that these farmers exhibit a relatively high degree of risk aversion, with an estimated coefficient of $\phi = 1.8$. This analysis highlights how farmers balance the risks associated with crop failures and income variability due to climatic uncertainties.The findings underscore the complexity of implementing adaptation strategies that minimize risks while ensuring long-term resilience. Ultimately, the study offers practical insights into how climate resilience can be strengthened through targeted interventions, focusing on both technological adoption and risk management for vulnerable farming communities.

Keywords: climate change, risk, adaptation, target MOTAD, resilience

1. Introduction

Climate change has become an undeniable reality for agriculture worldwide, but its effects are especially harsh in arid and semi-arid regions (Bogale et al., 2025), where water scarcity and soil degradation already limit productivity. In Morocco, where agriculture plays a central role in both the economy and rural livelihoods (Khoali et al., 2023), increasingly erratic rainfall, rising temperatures, and prolonged droughts have placed enormous stress on farming systems (Fahad & Wang, 2020; Usman et al., 2025). The Intergovernmental Panel on Climate Change ranks semi-arid zones among the most vulnerable globally, citing growing threats to food security and water availability (IPCC, 2021).

These pressures are deeply felt in Morocco's rural heartlands, where water shortages, made worse by recurrent dry spells, have led to declining yields and shrinking pasturelands. For instance, projections suggest that water availability could drop by 30% by 2050 (Boretti et al., 2019), a scenario that would have serious implications for already fragile rainfed agriculture. Soil degradation is another concern, erosion and nutrient loss, driven by unsustainable land use and climate extremes, have already caused yield reductions of over 20% in some areas (Benaly et al., 2025).

This environmental degradation translates into social and economic vulnerability, especially for smallholders who make up more than 80% of Moroccan farmers (Abdelmajid et al., 2021). Their limited access to credit, education, and climate-resilient technologies leaves them particularly exposed.

Various strategies have been proposed to cope with these changes, including crop diversification, conservation agriculture, agroecology, and the adoption of drought-tolerant crops (Ahmed et al., 2025). While promising, the success of these approaches depends on external support and farmers' willingness to take risks. Yet, risk aversion remains a major obstacle. As shown in some studies, smallholders in developing countries often choose low-risk, low-return strategies to avoid short-term losses even if it limits their ability to adapt in the long run (Deressa et al., 2011; Dinar et al., 2008).

In Morocco, this behavior is compounded by uncertainty about future weather patterns and a lack of financial security. Dinar found that Moroccan farmers frequently avoid investing in innovation because of their strong risk aversion, preferring familiar methods over newer, potentially more profitable practices (Dinar et al., 2008). Recognizing this challenge, the Moroccan government, supported by the World Bank, has worked to develop a more inclusive agricultural insurance system (Schuman et al., 2024). But adaptation alone is not enough; building resilience means developing systems that not only withstand shocks but also recover and improve in the face of them. As the FAO has emphasized, smallholders need more than weather forecasts and crop insurance (Canton, 2021), they need institutional support, knowledge-sharing platforms, and financial tools that empower them to innovate.

In this context, while climate variability directly affects crop yields, its economic impact is often reflected through fluctuating market prices. Therefore, this study uses price variability as a proxy for climate-induced income risk. By capturing the combined effects of yield uncertainty and market dynamics, the model provides a practical representation of the risks faced by smallholder farmers in semi-arid Morocco.

One promising avenue is the use of decision-support tools like farm-level economic models, which help visualize trade-offs under risk. The Target MOTAD model is one such tool, allowing researchers to simulate farm decisions under different income risk scenarios. It's been used to great effect in semi-arid contexts, including North Africa, to explore how farmers make choices when resources are limited and weather is uncertain (Benaly et al., 2025; Al-Nassr, 2019).

This study contributes to that body of work by applying the Target MOTAD model to the Oulad Boughadi region of Morocco. It focuses on how smallholder farmers balance risk and return in their land use, crop selection, and integration of livestock, considering real constraints like limited labor, credit, and land. By doing so, it aims to offer practical insights for sustainable rainfed agriculture in Morocco.

2. Methodology

2.1 Data Collection and Sources

This study was conducted during the 2021–2022 cropping season in a semi-arid region. A survey was administered to 80 smallholder farmers, yielding a comprehensive dataset involving quantitative and qualitative variables. These variables included detailed climate data, which were subsequently aggregated to correspond with key phases of the agricultural calendar. Given the farmers' complete reliance on rainfall, climatic variables played a critical role in assessing their adaptive responses to environmental uncertainty. Agronomic data contained crop yields and input requirements for principal crops, while economic indicators included farmgate prices, labor costs, and other relevant financial variables. Historical fluctuations in both yield and price levels were also recorded to assess underlying risk exposure. Furthermore, the dataset incorporated institutional and policy-related factors, such as access to credit and agricultural extension services. Collectively, these integrated datasets facilitated an in-depth analysis using the Target MOTAD model of smallholder farmers' risk preferences and resilience strategies in the face of climatic variability.

2.2 Study Area Description

This study was carried out in Oulad Boughadi community (Figure 1) characterized by low and erratic precipitation patterns and pronounced temperature variability (Driouech et al., 2020). The local economy is predominantly based on smallholder agriculture. The main crops are durum wheat, soft wheat, and barley. They are chosen for their relative drought tolerance and compatibility with the region's constrained natural resources. Despite these adaptive traits, agricultural production remains highly susceptible to climatic stressors, including extended dry spells and unpredictable rainfall onset, both of which have significant implications for yield stability. From a socioeconomic perspective, the region is marked by limited off-farm employment opportunities, restricted access to markets, and minimal institutional support. These environmental and socioeconomic challenges highlight the urgent need for the development and implementation of resilient farming systems capable of supporting smallholder adaptation under increasing climatic uncertainty.

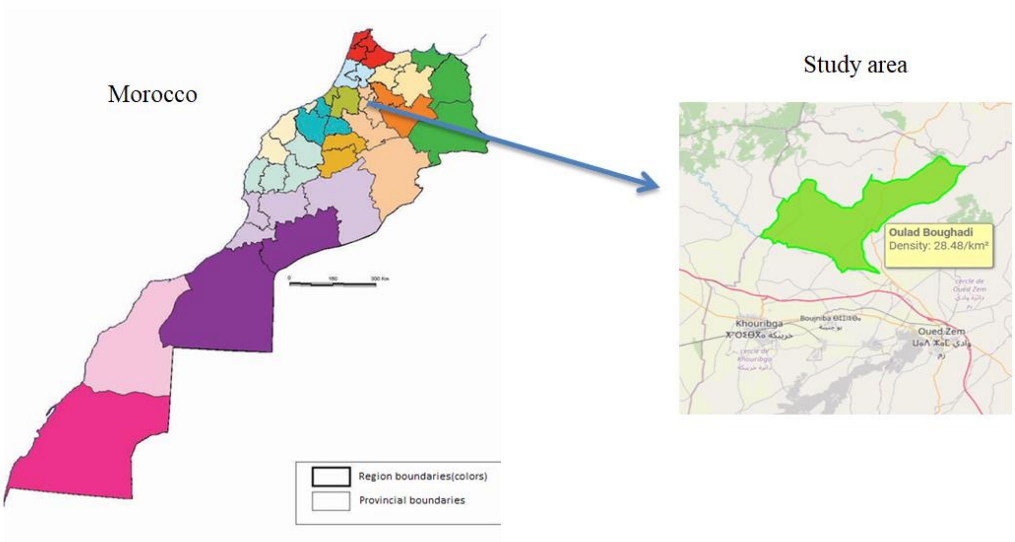

Figure 1. Study Area (Conseil Général du Développement Agricole, 2009)

2.3 Methodology

To model a such complex behavior, various approaches can be used, among which the Target MOTAD model was selected. The model provides a linear programming framework for optimizing expected income while minimizing deviations from a target income level (Hazell, 1971). This makes it especially useful in evaluating strategies under uncertainty in regions prone to environmental shocks. Target MOTAD has been widely applied in empirical research, for instance, to evaluate risk-adjusted cropping strategies in Tunisia (Chebil et al., 2015), to assess livestock-crop integration under uncertainty in Ethiopia (Molla et al., 2023)., and in Morocco's Chaouia and Tadla regions to analyze the trade-offs faced by risk-averse farmers (Sraïri et al., 2016; Laghrour et al., 2016; Baccar et al., 2017; Laamari, 2015)..

By incorporating the variability of climatic conditions and crop yields, the model allows for a nuanced understanding of how individual preferences such as risk aversion or risk tolerance shape agricultural choices. Moreover, it enables the identification of optimal strategies that reduce exposure to risk while promoting sustainable agricultural production. As such, the model serves as a valuable tool for assessing the resilience of farmers in the Oulad Boughadi study area.

Target MOTAD Model Formulation

The main source of risk affecting farm income in the study area is the variability of agricultural product prices. Climatic effects on production are assumed to be limited, whereas market price fluctuations are substantial and can significantly influence farmers' incomes. For this reason, the Target MOTAD approach is adopted, as it allows explicit modeling of income risk through deviations from expected returns while preserving linearity and computational tractability. The objective is to maximize expected net income while minimizing deviations from target returns.

Let *j* denote production activities (crops and livestock), *i* denote resources (land, labor, credit,

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fodder, etc.), and k denote states of nature representing different price scenarios. The sets C, A, M, SM, AL, and T represent crop activities, livestock units, months, states of nature, feed resource types, and cropping intensity, respectively. The decision variable X_j represents the level of activity j (expressed in hectares for crops and number of heads for livestock). The parameter $\overline{c_j}$ denotes the expected net return of activity j, while c_{kj} represents the realized net return of activity j under state of nature k. The variables dk^+ and dk^- measure the positive and negative deviations from expected income in each state. The parameter a_{ij} indicates the amount of resource i required by activity j, b_i denotes the maximum available amount of resource i, and Ψ represents the coefficient of absolute risk aversion (see table1).

The Target MOTAD model is formulated as:

$$Max\ Z \sum \overline{c_j} X_j - \Psi \sum_k (d_k^+ + d_k^-)$$

$$s.c. \quad \sum_j (c_{\{kj\}} - \bar{c}_j) X_j - d_k^+ + d_k^- = 0 \quad for\ all\ k$$

$$\sum_j a_{ij} X_j \leq b_i \quad for\ all\ i$$

$$X_j, \quad d_k^+, \quad d_k^- \geq 0 \quad for\ all\ \ k$$

The objective function maximizes expected farm income while penalizing deviations from expected returns, which represent income risk. The deviation constraints define income deviations for each price scenario. The resource constraints ensure that the use of land, labor, credit, fodder, and other resources does not exceed their available levels. The land constraint limits total cultivated area to the available farmland (15 ha). The labor constraint accounts for seasonal labor requirements and total available family and hired labor (approximately 180–250 man-days per year). The credit constraint limits total financing for production inputs to the available credit (5 000 MAD). Crop rotation constraints ensure agronomic feasibility, while fodder constraints guarantee minimum feed requirements for livestock activities.

Price uncertainty is represented by ten states of nature, derived from a ten-year historical series of agricultural product prices (2010–2019). For each state of nature (SM1–SM10), deviations from expected income are captured by the deviation variables dk^+ and dk^-, with the total absolute deviation given by $\sum k(dk^+ + dk^-)$ and weighted in the objective function by the risk-aversion coefficient Ψ. Monthly price variations within each year were aggregated to produce annual average prices, which were then used to construct crop-specific price indices.

Each state of nature reflects a distinct market scenario, encompassing both favorable and unfavorable price conditions, allowing the model to translate price variability into deviations from expected income. This linear formulation preserves computational tractability and can be solved using standard linear programming solvers, effectively capturing economic risk under semi-arid conditions.

Although the primary risk term in the model is price variability, it is closely linked to climate conditions: in the study region, rainfall variability strongly influences market prices through changes in crop yields and supply. Therefore, price variability serves as a practical proxy for climate risk, capturing the indirect effects of rainfall and other climatic factors on farm income. This approach maintains model tractability while still accounting for the main sources of uncertainty faced by farmers.

All equations were implemented in a mathematical programming environment and solved using appropriate linear optimization solvers.

Table 1. Notation of the Target MOTAD model

Symbol	Description
j	Production activities
i	Resources
k	States of nature
X_j	Activity level
$\bar{c}_j$	Expected net return
c_{kj}	Net return in state (k)
d_{k+}, d_{k-}	Deviations from expected income
a_{ij}	Resource use
b_i	Resource capacity
Ψ	Risk aversion
Z	Objective function value

3. Results

3.1 Farmers' Risk Behaviors

To identify the risk behavior of our selected farmers, different scenarios of risk aversion coefficients were used. This simulation undertakes an essential analysis of farmers' risk-related behavior in order to address two central research questions: (i) what degree of risk best reflects the decision-making patterns of farmers within the study area, and (ii) how resource allocation can be optimized across different levels of risk aversion. The risk-aversion coefficient $\phi = 1.8$ is adopted from previous empirical studies on semi-arid Moroccan farming systems (Sraïri et al., 2016; Baccar et al., 2017), which reported similar behavioral patterns among farmers. Sensitivity analysis across a range of values (–2.0 to 2.0) confirmed that ϕ = 1.8 represents a moderately risk-averse farmer, consistent with field observations in the Oulad Boughadi community. This parameter quantifies the degree to which farmers prioritize income stability over potential high returns. By varying the ϕ coefficient, a series of crop planning strategies were generated, each associated with a corresponding average income and standard deviation. The resulting objective function values (U) differ across scenarios, showing an upward trend as the analysis moves from risk-averse toward risk-preferring attitudes. This transition allowed for the estimation of risk premiums relative to the observed baseline scenario. As illustrated in the following table 2, the estimated risk premium ranges from approximately 5 000 MAD to as much as 45 000 MAD, a ninefold increase that, however, corresponds with a substantially elevated level of risk[1]. These findings contribute to a better understanding of the potential role of agricultural insurance and provide guidance for more effective strategies in land use and livestock management under varying risk conditions.

Table 2. Optimal expected farm income and risk premium under alternative Target MOTAD risk aversion levels (Ψ)

Risk aversion Ψ	Expected income U (MAD/farm/year)	Risk premium (MAD/farm/year)
2.0	139 866.42	4 866.36
1.8	141 861.20	6 861.14
1.6	143 855.99	8 855.93
1.4	145 850.77	10 850.71
1.2	147 845.56	12 845.49
1.0	149 840.34	14 840.28
0.8	151 835.12	16 835.06
0.6	153 829.91	18 829.85
0.4	155 824.69	20 824.63
0.2	157 819.48	22 819.41
0.01[2]	159 814.26	24 814.20
−0.2	161 809.04	26 808.98
−0.4	163 803.83	28 803.77
−0.6	165 798.61	30 798.55
−0.8	167 793.40	32 793.33
−1.0	169 788.18	34 788.12
−1.2	171 782.96	36 782.90
−1.4	173 777.75	38 777.69
−1.6	175 772.53	40 772.47
−1.8	177 767.32	42 767.25
−2.0	179 762.10	44 762.04

Table 3 reports the optimal expected annual farm income (U) and the corresponding risk premium under alternative values of the Target MOTAD risk aversion coefficient (Ψ). Increasing Ψ reflects higher risk aversion, leading to lower expected income and a reduced risk premium. The simulated scenarios reveal a clear relationship between the level of risk

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[1] Note that risk premium vary from 334 to 3000 MAD per hectar.

[2] Risk can never be entirely eliminated and therefore cannot be assumed to be equal to zero.

aversion (ϕ) and the resulting value of the objective function (U), shedding light on how farmers adjust their decisions in response to uncertainty. At the highest level of risk aversion (ϕ = 2.0), the objective function reaches approximately 139 866.42 MAD, reflecting a conservative strategy in which potential earnings are reduced in favor of income stability and lower exposure to risk. As the aversion coefficient declines to ϕ = 1.0, U increases to 149 840.34 MAD, indicating a moderate risk posture in which farmers are willing to tolerate some income variability in exchange for improved returns. Under a near risk-neutral scenario (ϕ = 0.01), the objective function reaches 159 814.26 MAD, implying that decisions are guided primarily by expected income, with minimal consideration of risk. When ϕ takes negative values, such as −1.0 and −2.0, U rises to 169 788.18 MAD and 179 762.10 MAD, respectively, representing risk-seeking behavior whereby farmers actively pursue higher returns despite substantial income variability. These variations in U across different risk profiles demonstrate how risk preferences critically shape both strategic choices and income outcomes in agricultural production systems.

This study on risk management in the Oulad Boughadi community highlights key behavioral patterns among farmers facing climatic uncertainty. In line with previous research conducted in Morocco, particularly in rainfed and semi-arid regions, the findings confirm that risk preferences strongly influence agricultural decision-making. Risk-averse farmers favor conservative strategies, opting for resilient but lower-return crops such as durum wheat and barley in order to stabilize income under erratic rainfall conditions. This behavior is consistent with the findings of Sraïri et al. (2016) in the Chaouia and Tadla regions. In contrast, farmers with higher risk tolerance pursue higher-value crops despite greater income volatility, a trend also reported by Baccar et al. (2017) in Meknès.

Sustainable land and water management practices, such as the integration of legumes, are more common among risk-averse farmers seeking to mitigate drought impacts. These findings support Laghrour et al. (2016), who emphasized the importance of soil conservation in similar agro-climatic zones. Livestock integration also emerges as a critical resilience strategy, providing a stable income source and enabling efficient use of agricultural by-products. This observation echoes the conclusions of Guesmi et al. (2019), who highlighted the role of livestock in income security and resource optimization in North African farming systems.

Overall, the results demonstrate that farmers' strategic choices in semi-arid environments are closely linked to their risk attitudes, with important implications for sustainable agricultural planning and resilience-building. Moreover, the model outcomes are consistent with the Expected Mean Variance (EMV) framework, which combines expected returns and income variability to guide optimal decision-making.

3.2 Decision Making for Risk Averse Farmers (ϕ = 1.8)

The marginal values of ressources used in the process of production are an important indicator of the decision making process with the objective of increasing or stabilising the profit.

Income Standard Deviation:

In addition to the profit generated by the model, the standard deviation of income is estimated at 1 800 MAD/ha, indicating a high level of economic risk linked to climatic variability and price volatility. A higher standard deviation reflects greater income dispersion, and thus increased uncertainty in expected returns. This metric is critical for evaluating the model's overall risk exposure. In this case, the elevated income variability suggests that future revenues are highly sensitive to external shocks, such as fluctuating market prices, variable yields, and other climatic or economic factors.

Key variables influencing this volatility include labor, inputs, and land availability, all of which shape both production and marketing decisions. Strategies to reduce income risk could involve crop diversification and the development of price and input support mechanisms, potentially cushioning farms against adverse economic scenarios and enhancing income stability.

Objective Function (U) and Average Income (Z):

The objective function is optimized at 141 861.19 MAD, which corresponds to the maximum value obtained by the model under the selected risk aversion level. The average income (Z), computed as the mean income across the different economic scenarios, reaches 159 814.26 MAD (Table 3). This value represents the expected farm income under variable market conditions. Although the projected average income is relatively high, the associated income variability, captured by the standard deviation, indicates a non-negligible level of income risk. Consequently, further research could focus on strategies aimed at reducing the underlying sources of variability in order to enhance income stability and improve the robustness of projected returns.

Table 3. Optimized economic indicators of the Target MOTAD model (MAD)

Parameter	Value (MAD)
Average income (Z)	159 814.26
Standard deviation (STDEV)	9 973.92
Objective function (U)	141 861.19

Income by State of Nature (ZV):

The various states of nature (SM1 to SM10) represent different market scenarios that may result in either a positive or negative marginal income value, as illustrated in the table below. The magnitude of this marginal value reflects the contribution of each state of nature particularly price fluctuations to the increase or decrease of the risk-adjusted income. This variation highlights the sensitivity of farm income to market volatility and underscores the importance of incorporating price risk into agricultural planning models.

Table 4. Income by State of Nature (SMk) (values in MAD)

State of Nature (SMk)	Income Zk (MAD)	Marginal Value
SM1	161 320	0.027
SM2	159 010	−0.015
SM3	164 990	0.093
SM4	163 910	0.074
SM5	138 080	−0.392
SM6	152 990	−0.123
SM7	143 130	−0.301
SM8	151 720	−0.146
SM9	156 320	−0.063
SM10	151 270	−0.154

The states of nature (SM1–SM10) represent alternative market price scenarios. Table 4 reports the corresponding income levels (Zk) and their marginal contributions to the objective function. The marginal values indicate whether each price scenario improves or deteriorates risk-adjusted farm income. Positive marginal values are observed for SM1, SM3 and SM4, indicating favorable price conditions that increase income. These scenarios generally correspond to early-season marketing periods when cereals from the previous harvest are sold and farmers revise expectations based on emerging market and climatic signals. Negative marginal values are observed in seven out of ten scenarios, with the lowest value reaching −0.392 under SM5. This indicates that in most market situations, price variability tends to reduce farm income. The predominance of negative marginal values confirms that market volatility constitutes a major source of economic risk in the study area. Limited marketing alternatives force farmers to sell under unfavorable price conditions, increasing their exposure to income losses. The model indicates that 70% of the simulated price scenarios are associated with income deterioration, reflecting a predominantly risk-averse behavior, consistent with previous empirical findings for semi-arid Moroccan regions (Moussaoui, 1994).

Cultivated Crop Areas (in ha)

Table 5. Optimal Cultivated Crop Areas and Marginal Values (MAD/ha)

Crop	Optimal Area (ha)	Actual Area (ha)	Marginal Value (MAD/ha)
Soft Wheat	1.148	3.00	0.000
Durum Wheat	5.220	2.50	1 150.00
Forage Pea	4.819	2.00	1 020.00
Barley	3.671	3.00	950.00
Olive Trees	0.143	0.40	120.00
Oats	0.000	1.00	−1 830.00
Fallow	0.000	2.00	−2 046.71

Table 5 presents the optimal land areas allocated to each crop, as determined by the model, along with the marginal values reflecting each crop's contribution to the objective function. Positive marginal values indicate crops that improve income, while negative values signal economically inefficient crops. For instance, durum wheat (1 150 MAD/ha) and forage peas (1 020 MAD/ha) contribute strongly to farm income, whereas oats (−1 830 MAD/ha) and fallow (−2 046.71 MAD/ha) would reduce overall income if included. This suggests that oats and fallow are economically inefficient under the current optimization framework, likely due to low profitability or high production costs. Replacing them with higher-return crops or reallocating land to more profitable alternatives could enhance overall system performance.

The allocation also reflects a strategic prioritization based on crop suitability and resilience:

- **Durum wheat (34.80%)** and **forage peas (32.12%)** occupy the largest areas, benefiting from semi-arid adaptability. Forage peas also improve soil fertility through nitrogen fixation.
- **Barley (24.47%)** is valued for drought tolerance and dual-use (grain and forage).
- **Soft wheat (7.65%)** and **olive trees (0.95%)** receive smaller allocations, reflecting higher input requirements, labor intensity, or sensitivity to climate fluctuations affecting flowering and yield quality.

Overall, this allocation strategy balances economic returns, climate resilience, and risk mitigation. Integration with livestock and conservation agriculture practices, such as direct seeding, further supports labor and cost efficiency while reducing exposure to risk. In this framework, durum wheat and barley emerge as key crops supporting farm resilience in semi-arid agroecosystems.

Livestock Inventory on the Farm

Table 6. Livestock Inventory: Optimal vs. Actual

Animal Type	Optimal Total Number	Actual Total Number	Marginal Value (MAD/unit)
Livestock Units (LU)	3.645	3.00	0.00

Table 6 presents the livestock inventory on the farm. The optimal total number of 3.645 livestock units (LU) is determined by the model based on resource and economic constraints, classifying the farm as a small-scale operation in terms of herd size. The marginal value of livestock units is zero, indicating that within the current model, variations in herd size do not significantly influence the objective function. However, increasing the herd could affect long-term profitability depending on additional feed, labor, and veterinary costs. This highlights that while livestock contributes to farm resilience and income stability, its impact on the optimization outcome is limited under the current assumptions and resource availability. Future scenarios incorporating feed constraints, seasonal labor, or market prices for livestock products could reveal a stronger influence of herd size on farm income.

Animal Feed Purchases (in kg)

Table 7. Optimal Feed Purchases for Livestock (kg)

Feed Type	Optimal Purchases (kg)	Actual Purchases (kg)	Marginal Value (MAD/kg)
Barley Grain (orgg)	3 519.37	3 000.00	0.00
Bread Residue (psec)	2 778.45	2 500.00	0.00
Bran (sn)	2 994.55	2 800.00	0.00
Sugar Beet (psb)	3 118.04	2 900.00	0.00

Table 7 presents the optimal quantities of feed purchased for livestock. The model identifies the reported values as the most efficient allocation under current resource and economic constraints. All feed types exhibit marginal values effectively equal to zero, indicating that slight increases or decreases in purchase quantities would have minimal impact on the overall objective function. This suggests that the current feed supply is well-calibrated to the herd's needs, providing adequate nutrition while optimizing costs. Adjustments to feed purchases would only be necessary under significant changes in livestock numbers, market prices, or feed availability.

Monthly Distribution of Labor Requirements

Table 8. Monthly Labor Requirements (man-days)

Month	Optimal Labor (units)	Actual Labor (units)	Marginal Value (MAD/unit)
M1	26	25	0.00
M2	28	28	0.00
M3	45	40	0.00
M4	47	44	0.01
M5	15	14	0.00
M6	41	39	0.00
M7	8	7	0.00
M8	7	6	0.00
M9	5	5	0.00
M10	6	6	0.00
M11	53	52	0.00
M12	28	27	0.00

Table 8 shows the distribution of labor requirements across the 12-month planning horizon. Labor use varies throughout the year, reflecting seasonal crop and livestock activities.

For example, in Month 1 (M1), labor utilization is 26 units, well below the maximum available capacity of 103 units, suggesting that unused labor could be strategically allocated to other productive tasks, potentially improving overall farm efficiency.

The marginal value of labor is only relevant in Month 4 (0.01 MAD/unit), indicating extremely low sensitivity. This implies that a slight increase in labor availability during M4 would have a negligible impact on the objective function. For all other months, the marginal value is effectively zero, confirming that the existing workforce is sufficient to meet production requirements throughout the year.

3.3 Discussion

This model highlights several key constraints affecting farm performance in the Oulad Boughadi community. Farmers typically base crop planning decisions on land, labor, and financial capital, while climatic conditions, although influential, are considered a general constraint in this context. The model allows simulation of different risk preferences, showing how farmers adjust strategies under uncertainty. For example, the risk-averse scenario ($\phi = 2.0$) aligns closely with observed behavior in the community, where farmers prioritize stability, cultivating drought-tolerant crops such as durum wheat and barley, and allocating land to fodder peas to support livestock nutrition and maintain soil fertility. Less risk-averse or risk-tolerant scenarios ($\phi = 0$ to -1.0) would encourage more aggressive income-seeking behavior, such as expanding high-return crops or experimenting with new technologies, though these are less representative of the typical semi-arid smallholder practices observed.

The liquidity constraint reflects a working capital of 25 000 MAD for essential inputs, while the model recommends an optimal credit of 35 912.59 MAD to implement the cropping plan. The labor constraint is generally non-binding, with the highest demand of 53.68 person-days in August, associated with harvest and post-harvest activities. The land constraint emerges as the most limiting factor, with a high marginal value of 9 523.35 MAD, indicating that additional land could substantially increase farm income. The fodder constraint is met with an optimal availability of 63 293.7 forage units (UF), ensuring adequate livestock nutrition.

In terms of crop allocation, the model selects durum wheat (5.22 ha), fodder peas (4.82 ha), and barley (3.67 ha), reflecting adaptation to water scarcity and economic priorities. Durum wheat and barley are drought-tolerant, while soft wheat benefits from policy incentives, such as subsidized inputs. Since 2010, conservation agriculture practices, including direct seeding and agroforestry, have encouraged cereal and forage production.

Fodder peas contribute to soil fertility through nitrogen fixation, reduce reliance on chemical fertilizers, and provide valuable livestock feed. Barley, though less productive, serves both as grain and forage, supporting household food and fodder needs. The limited allocation to olive trees and absence of fallow reflect their lower short-term income contributions; however, fallow and legume rotations provide crucial ecosystem services, including soil regeneration and water retention. These results suggest that policy-driven incentives are necessary to promote sustainable practices.

The average income predicted by the model is 159 814.00 MAD, with a marginal return of 10 654.26 MAD/ha, a modest yet achievable outcome under challenging conditions. The model indicates that meaningful income improvements would require land expansion and supplementary irrigation, aligning with Morocco's Green Generation 2021–2030 agricultural strategy.

To mitigate climate risks, such as rainfall irregularity and drought, the model supports crop diversification, integrating perennial species like olive trees and cover crops during fallow periods. These measures enhance soil quality and biodiversity. Agroforestry and crop rotation further improve resilience by combining annual and perennial production while protecting soil. Conservation practices such as minimum tillage and agroforestry reduce erosion, improve water retention, and lower fertilizer dependence.

Cooperatives and farmer associations in the region play a pivotal role in promoting innovation facilitating access to drought-tolerant seeds, modern equipment, and competitive markets. They also strengthen the economic viability of small farms, supporting the resilience of agricultural systems under changing climate and resource conditions. These observations are consistent with the model's outputs, which show that risk-averse farmers strategically allocate crops and resources to stabilize income while maintaining long-term sustainability.

4. Conclusion

In the Oulad Boughadi community, where agricultural activity is highly dependent on rainfall, managing climate-related risks is essential for the resilience of farming systems. This study demonstrates that the adoption of risk management practices is a key pathway for enhancing agricultural resilience. The application of the Target MOTAD model provided a quantitative assessment of both climatic and economic risks, illustrating how optimal resource allocation under uncertainty can support more informed and resilient decision-making.

The model results indicate that farmers in the study area, characterized by a risk aversion coefficient of $\phi = 1.8$, tend to adopt conservative strategies aimed at stabilizing income under variable climatic conditions. Crop diversification and livestock integration emerged as pivotal strategies for buffering against income volatility and promoting long-term sustainability. The analysis further highlights that expanding land availability, adopting conservation agriculture, and integrating perennial legumes could enhance both income stability and environmental resilience.

Overall, the findings underscore the critical role of diversified agricultural practices in adapting to climate variability in semi-arid environments. While technological innovations can improve productivity and risk management, they are insufficient on their own. A coordinated policy framework is needed, including agricultural price stabilization, targeted subsidies, financial incentives for adaptive practices, and strengthened value chains through cooperative engagement and local product processing.

Ultimately, a holistic approach that combines technological innovation, institutional support, and value chain development is required to mitigate the long-term impacts of climate change on agriculture in regions such as Oulad Boughadi.

While these findings provide valuable insights into farm decision-making under risk, it is important to note that the analysis is based on a single community of 80 farms, and the model does not explicitly account for yield variability or all stochastic climatic factors. Future research could expand the study to multiple communities, incorporate more detailed climatic and yield data, and explore additional risk management strategies to further enhance the robustness and applicability of the results.

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Author contributions

Dr. Safwa Khoali: data curation, methodology, formal analysis and writing - original draft; Dr.

Laamari Abdelali: data curation, writing - review & editing, and validation; supervision and conceptualization. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

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The Publication Ethics Committee of the Macrothink Institute.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

References

Abdelmajid, S., Mukhtar, A., Baig, M. B., & Reed, M. R. (2021). Climate Change, Agricultural Policy and Food Security in Morocco. In: Behnassi, M., Barjees Baig, M., El Haiba, M., Reed, M.R. (eds) Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa. Springer, Cham. https://doi.org/10.1007/978-3-030-72987-5_7

Ahmed, O., Faiz, M., Abdelali, L., Khoali, S., Pulvent C., Mohamed, S., … & Glauben, T. (2025). Unlocking climate change resilience: Socioeconomic factors shaping smallholder farmers' perceptions and adaptation strategies in Mediterranean and Sub-Saharan Africa regions. *Regional Sustainability, 6*(1), 100195. https://doi.org/10.1016/j.regsus.2025.100195

Al-Nassr, R. S. M. (2019). Using MOTAD model to determine efficient production plans in Al-Kadhimiya agriculture division farms under risk and uncertainty conditions 2012-2017. *Iraqi Journal of Agricultural Sciences*, *50*(5). https://doi.org/10.36103/ijas.v50iSpecial.183

Baccar, M., Bouaziz, A., Dugué, P., & Le Gal, P. Y. (2017). Shared environment, diversity of pathways: dynamics of family farming in the Saïs Plain (Morocco). *Regional environmental change*, *17*, 739-751. https://doi.org/10.1007/s10113-016-1066-4

Benaly, M. A., Brouziyne, Y., & Kharrou, M. H. (2025). Modeling climate impacts on crop yields in semi-arid Morocco. *Mitigation and Adaptation Strategies for Global Change*. https://doi.org/10.1007/s11027-025-10199-9

Bogale, G. A., Kassa, A. K., & Maja, M. M. (2025). Changes in climate extreme indices and agricultural drought monitoring in the semi-arid areas of Borana zone, southern Ethiopia. *Heliyon, 11*(4), e042179. https://doi.org/10.1016/j.heliyon.2024.e042179

Boretti, A., & Rosa, L. (2019). Reassessing the projections of the World Water Development Report. *npj Clean Water, 2*(15). https://doi.org/10.1038/s41545-019-0039-9

Canton, H. (2021). Food and agriculture organization of the United Nations—FAO. In *The Europa directory of international organizations 2021* (pp. 297-305). Routledge. https://doi.org/10.4324/9781003179900-41

Chebil, A., Frija, A., & Thabet, C. (2015). Economic efficiency measures and its determinants for irrigated wheat farms in Tunisia: a DEA approach. *New medit*, *14*(2), 32-38.

Conseil Général du Développement Agricole. (2009). Agricultural map of Morocco. [Online map].

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2011). Perception of climate change and adaptation of smallholder farmers in the Nile Basin of Ethiopia. *Global Environmental Change, 19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Dinar, A., Hassan, R., Mendelsohn, R., Benhin, J., & al, E. (2008). Climate Change and Agriculture in Africa: Impact Assessment and Adaptation Strategies (1st ed.). Routledge. https://doi.org/10.4324/9781849770767

Driouech, F., ElRhaz, K., Moufouma-Okia, W., Arjdal, K., & Balhane, S. (2020). Assessing future changes of climate extreme events in the CORDEX-MENA region using regional climate model ALADIN-climate. *Earth Systems and Environment*, *4*(3), 477-492. Conseil Général du Développement Agricole. (2009). *Atlas de l'Agriculture Marocaine* (Édition 2008). Ministère de l'Agriculture et de la Pêche Maritime. Imprimé en avril 2009.

Fahad, S., & Wang, J. (2020). Climate change, vulnerability, and its impacts in rural Pakistan: a review. *Environmental Science and Pollution Research*, *27*, 1334-1338. https://doi.org/10.1007/s11356-019- 06878-1

Guesmi, H., Ben Salem, H., & Moujahed, N. (2019). Integration crop-livestock under conservation agriculture system. *Agri & BioTech*, *65*(1).

Hazell, P. B. R. (1971). A linear alternative to quadratic and semivariance programming for farm planning under uncertainty. *American Journal of Agricultural Economics, 53*(1), 53–62. https://doi.org/10.2307/1237720

IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Khoali, S., Lakhyar, Z., Laamari, A., & Faris, H. (2023). Analyse de la performance et de l'efficience des exploitations agricoles de la région Tadla. *AFRIMED AJ – Al Awamia*, 140, 75-94.

Laamari, A. (2015). Etude Données de base des Légumineuses alimentaires au Maroc: Analyse de l'offre, coûts de production et indicateurs de performance. *Morocco-Indian for the Development of Food Legumes Initiative Rapport*, 1-74.

Laghrour, M., Moussadek, R., Mrabet, R., Dahan, R., El-Mourid, M., Zouahri, A., & Mekkaoui, M. (2016). Long and midterm effect of conservation agriculture on soil properties in dry areas of Morocco. *Applied and Environmental Soil Science*, *2016*(1), 6345765. https://doi.org/10.1155/2016/6345765

Molla, E., Melka, Y., & Desta, G. (2023). Determinants of farmers' adaptation strategies to climate change impacts in northwestern Ethiopia. *Heliyon*, *9*(8), e18514. https://doi.org/10.1016/j.heliyon.2023.e18514

Moussaoui, M. (1994). *An ex ante evaluation of the interaction between risk behavior and technology adoption in Morocco's dryland agriculture: The case of bread wheat supplementary irrigation*. The University of Nebraska-Lincoln.

Schuman, I., Trier, R., Gourroum, N., Berger, C., Bouaziz, Y., Forget, V., Cerruti, C., Aboudajdine, R., Bennani, F., Cordier, J., Stoppa, A., Psaltopoulos, D., Dick, W., Cordier, J.,

Sraïri, M. T., Karrou, M., & Lyoubi, R. (2016). Farmers' risk management strategies in Moroccan rainfed agriculture. *Cahiers Agricultures*, 19(2), 89–95. https://doi.org/10.1684/agr.2010.0391

Usman, U., Yang, X., & Nasir, M. I. (2025). Role of climate change in economic uncertainty of Pakistan: New approach with qualitative comparative analysis. *Heliyon, 11*(4), e042517. https://doi.org/10.1016/j.heliyon.2025.e042517