Evaluating adaptive strategies for Mediterranean agriculture: a participatory approach in the Arroyo de la Balisa Sub-basin (Segovia, Spain)

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Abstract

Climate change is already exacerbating water scarcity issues, particularly in vulnerable regions such as the Mediterranean. In this context, agricultural adaptation measures are essential to ensure food security and sustainable agriculture. This research focuses on the prioritization and socioeconomic assessment of adaptation strategies for agriculture in the Arroyo de la Balisa sub-basin (Segovia, Spain). A participatory multi-criteria approach was conducted with 41 local stakeholders, including public administration, agronomic engineering companies, farmers, livestock producers, environmentalists, and experts, who ranked 14 adaptation measures under current and future scenarios. Subsequently, a structured questionnaire collected detailed insights from local farmers regarding socioeconomic impacts and implementation barriers for the eight prioritized measures. Key findings indicate that, despite their considerable

potential benefits, irrigation-related measures such as modernization and expansion are hindered by high costs and significant implementation barriers. Conversely, cover crops for woody crops and crop rotation with soil-improving species emerged as the most feasible options due to balanced cost-benefit perceptions among farmers. The participatory approach adopted, involving active validation by local actors, provided context-specific insights and enhanced the practical relevance and acceptance of results, facilitating targeted policy interventions to foster climate resilience in Mediterranean agriculture.

Keywords Climate change, adaptive measures, sustainable agriculture, social participation, perception analysis

JEL code Q180 Agricultural Policy; Food Policy; Animal Welfare Policy

1. Introduction

Climate change is exacerbating water scarcity issues, particularly in vulnerable regions such as the Mediterranean area, where the urgent implementation of adaptive agricultural and livestock measures is essential to contribute to food security and agricultural sustainability (Nikolaou et al., 2020). One key aspect of effective adaptation lies in improving water use efficiency through agronomic practices and advanced technologies (Alharbi et al., 2024). Among these measures, the implementation of advanced irrigation systems, the introduction of more resilient crop varieties, effective soil water management, and practices such as crop rotation or cover crops stand out (UnNisa et al., 2022). However, for the successful adoption of these strategies, the active participation of local communities is crucial to ensure their relevance and alignment with local realities (Iglesias & Garrote, 2018).

This study is part of the AGUAGRADA project (Jiménez-Aguirre et al., 2024) and focuses on the prioritization and socioeconomic assessment of agricultural adaptation measures to climate change, pursuing the following specific objectives: 1) Prioritization of agricultural adaptation measures to climate change through a multi-criteria analysis based on contributions from a multidisciplinary group of local stakeholders; 2) Socioeconomic assessment of the prioritized adaptation measures, based on information provided by farmers and livestock producers in the SCAB through a structured questionnaire.

2. Methodology

2.1. Case study

This research focuses on the case of the Arroyo de la Balisa Sub-basin (SCAB), located within the Duero Basin in Segovia, Spain (Figure 1). The SCAB covers an area of 242 km² and has a sub-arid Mediterranean climate characterized by very dry summers and an average annual precipitation of 427 mm/year. Approximately 70% of the SCAB area is devoted to agriculture, predominantly rainfed cereal crops such as barley and winter wheat. In contrast, irrigated agriculture currently occupies only a minor area, although it is expanding (Rivas-Tabares et al., 2019).

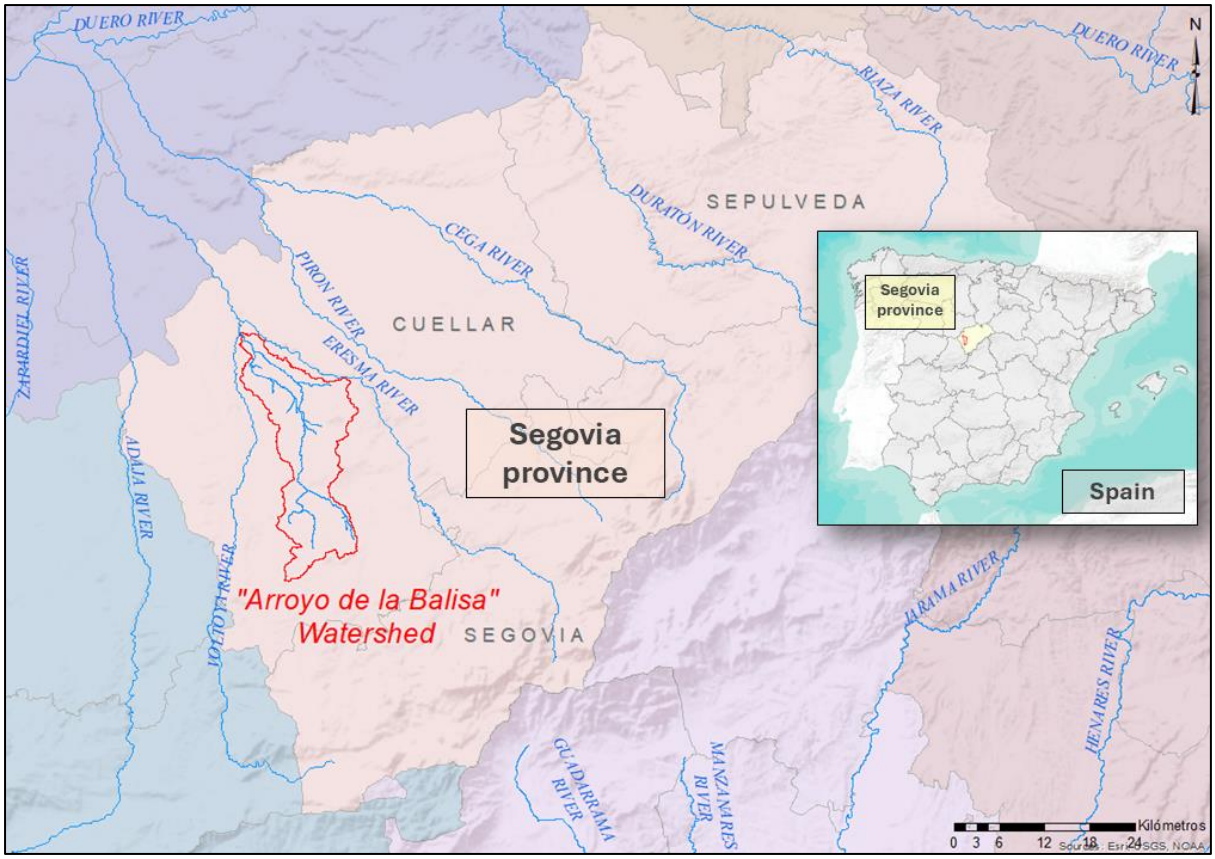

Figure 1. Case study area.

2.2. Prioritization of adaptation measures

To prioritize agricultural adaptation practices to climate change, a workshop was held in March 2024 in Segovia, with the participation of 41 stakeholders associated with the agricultural sector in the study area. These stakeholders represented various groups including public administration, agricultural engineering companies, farmers, livestock producers, environmentalists, and experts. During the workshop, these local actors contributed to the following activities:

Firstly, participants validated a pre-selection of adaptation measures proposed by the AGUAGRADA research team. These measures include: 1) modification of crop calendar (MCC); 2) change of crop varieties (VAR); 3) crop substitution (CRO); 4) conversion from rainfed to irrigated farming (IRR); 5) modernization of irrigation systems (MOD); 6) precision agriculture (PRE); 7) supplementary irrigation (SUP); 8) grazing on cover crops (GCC); 9) grazing on stubble (GST); 10) on-farm livestock feed production (LFP); 11) crop rotation with soil-improving species (ROT); 12) no-till farming (NTF); 13) cover crops for woody crops (COV); and 14) extensive grazing (EXT).

Secondly, participants distributed 100 points across four criteria related to adaptation measures (effectiveness, economic benefit, environmental benefit, and ease of implementation) to weight their relative importance when evaluating the proposed measures. Subsequently, for each of these criteria, participants allocated an additional 100 points among the proposed measures based on their performance concerning each criterion. This scoring was conducted for both a "current scenario" and a "future scenario" (characterized by increased evapotranspiration and reduced water availability due to climate change).

For each adaptation measure, a final score was calculated separately for the current and future scenarios, allowing the establishment of rankings in each case. These final scores were computed as a weighted average of the criterion-specific values, reflecting the relative importance assigned to each criterion. The scores for each criterion were determined by averaging the assessments provided by each stakeholder group.

2.3. Socioeconomic assessment of prioritized adaptation measures

For the socioeconomic evaluation of the prioritized measures, a structured questionnaire was designed to interview a representative sample of farmers and livestock producers from the SCAB (150 surveys), aiming to collect information on the aspects detailed in Table 1. Respondents were asked to rate the expected intensity of change for each item on a scale from -5 (very strong reduction) to +5 (very strong increase) in the event that the measure was adopted. If they anticipated no change, they were asked to indicate it with a 0.

The 17 items analyzed in the questionnaire are grouped into four thematic blocks: 1) aspects related to income; 2) environmental benefits, and climatic and biological resilience; 3) aspects related to costs; and 4) barriers to the implementation of adaptive measures. The first two blocks represent positive impacts (benefits or advantages for farms), while the last two represent negative impacts (disadvantages for farms or difficulties in implementing the adaptive measures).

In addition to these assessments, the survey gathered data on the profile of the respondents (main activity, age, sex, etc.), as well as on the characteristics of their farms (type of crops or livestock, farm size, head of livestock, etc.). Finally, participants also provided insights into potential incentives to facilitate the adoption of adaptation measures.

Table 1. Questions from the structured questionnaire for the assessment of prioritized measures.

Questions	Items	
How do these measures affect these **aspects related to income**?	▪ Crop yield/ livestock productivity ▪ Product quality	▪ Access to subsidies ▪ Access to more profitable markets
How do these measures affect these **environmental benefits, and climatic and biological resilience**?	▪ Water savings ▪ Soil health	▪ Drought resilience ▪ Resistance to pests and diseases ▪ Frost resilience
How do these measures affect these **aspects related to costs**?	▪ Initial investment ▪ Water use ▪ Energy use	▪ Inputs (fertilizers, pesticides, etc.) ▪ Machinery rental ▪ Labor
To what extent do the following factors act as **barriers to the implementation of these adaptive measures**?	▪ Need for training	▪ Administrative barriers

Source: own elaboration.

As of the submission date of this study, data is available from only 53 questionnaires, representing one-third of the total planned interviews. The preliminary results from these questionnaires were analyzed to assess the feasibility of the adaptive measures, based on the impact of the prioritized measures on each item and thematic block, according to the perceptions of SCAB farmers. Additionally, the relative importance that farmers assigned to different types of incentives to promote the implementation of adaptive measures was examined.

3. Results and discussion

3.1. Prioritization of adaptation measures

Table 2 presents the weights assigned by local stakeholders to the selected criteria for evaluating the proposed measures. First, the results are shown by stakeholder group, and at the end, the average results per group are included. These averages were used to calculate the final scores (Table 3).

Table 2. Relative importance assigned to each criterion in the evaluation of the measures.

Stakeholder group	Effectiveness	Economic benefit	Environmental benefit	Ease of implementation
Public administration	27.50	20.00	45.00	7.50
Companies	10.00	70.00	10.00	10.00
Farmers	25.71	40.00	20.00	14.29
Livestock producers	37.22	26.11	20.56	16.11
Environmentalists	20.00	50.00	20.00	10.00
Experts	30.00	26.00	28.00	16.00
Average	**25.07**	**38.69**	**23.93**	**12.32**

Source: own elaboration.

For local stakeholders, economic benefit carries the greatest weight, accounting for approximately 39%. This criterion was selected as the most decisive by representatives of businesses (70%), environmentalists (50%), and farmers (40%). This result reinforces the notion that farmers are more likely to adopt these measures when they perceive an economic benefit (Muench et al., 2024).

On the other hand, effectiveness and environmental benefit received similar weightings, with 25% and 24%, respectively. Effectiveness was chosen as the most relevant criterion by livestock producers (37%) and experts (30%), while environmental benefit was highlighted as the most important by public administration representatives (45%). In contrast, ease of implementation was the least relevant criterion for all groups (12%).

The scores obtained for each measure, both for the current scenario (CS) and the future scenario (FS), are presented in Table 3, ordered from highest to lowest. According to the weighted averages ($\bar{x}$*), the highest-rated measure for climate change adaptation was the modernization of irrigation systems (CS: 17.5; FS: 13.5). These results highlight irrigation modernization as a key measure for improving water productivity, primarily by significantly reducing water losses and ensuring optimal irrigation application (Nikolaou et al., 2020; UnNisa et al., 2022).

Several measures stand out, including the conversion from rainfed to irrigated farming (CS: 13.1; FS: 7.7), crop substitution (CS: 9.1; FS: 13.0), variety change (CS: 7.7; FS: 12.7), crop rotation (CS: 10.9; FS: 11.6), and no-till farming (CS: 8.5; FS: 11.2), whose relevance fluctuates depending on the scenario. Measures requiring advanced technologies or infrastructure to increase water efficiency or availability are more favorably received in the short term than in the long term, particularly in the case of conversion from rainfed to irrigated farming, likely due to the expected reduction in water availability in the future, which would hinder the establishment of new irrigation systems.

The opposite trend is observed with the introduction of more resilient crop varieties and sustainable practices such as rotation with soil-improving species or no-till farming, which receive higher evaluations under the scenario characterized by more frequent and extreme

drought periods. Meanwhile, measures related to livestock farming received the lowest ratings, likely due to the low representation of livestock producers in the workshop.

Table 3. Scores of adaptation measures for the current scenario (left) and the future scenario (right).

Current scenario (CS)						Future scenario (FS)					
Measure	**Effect.**	**Econ. Benef.**	**Env. Benef.**	**Ease of implem.**	**$\bar{x}$***	**Measure**	**Effect.**	**Econ. Benef.**	**Env. Benef.**	**Ease of implem.**	**$\bar{x}$***
MOD	16.8	19.8	16.5	14.0	**17.5**	MOD	14.4	14.3	11.5	13.1	**13.5**
IRR	12.4	15.9	10.0	11.4	**13.1**	CRO	13.9	15.7	8.0	12.4	**13.0**
ROT	10.3	9.1	13.5	12.6	**10.9**	VAR	14.3	14.1	9.0	12.1	**12.7**
CRO	8.1	10.4	7.7	9.7	**9.1**	ROT	10.9	10.4	11.1	17.7	**11.6**
NTF	9.7	6.3	12.3	5.7	**8.5**	NTF	10.2	7.4	19.2	9.6	**11.2**
MCC	9.4	8.0	4.1	10.9	**7.8**	MCC	11.3	7.8	4.2	11.2	**8.2**
VAR	10.3	7.0	5.7	8.7	**7.7**	IRR	7.8	10.4	5.0	3.9	**7.7**
COV	4.2	3.2	8.2	5.4	**4.9**	SUP	4.7	4.7	8.6	1.7	**5.3**
PRE	4.5	4.8	5.7	3.9	**4.8**	PRE	4.6	4.0	4.8	5.0	**4.4**
SUP	3.0	5.7	4.4	3.9	**4.5**	COV	3.2	2.6	7.4	2.2	**3.8**
LFP	4.8	2.8	3.6	4.5	**3.7**	EXT	1.9	2.8	3.1	4.5	**2.9**
EXT	2.3	2.3	3.5	3.8	**2.7**	GCC	1.1	1.9	2.6	3.2	**2.0**
GCC	2.3	2.7	2.5	2.8	**2.5**	LFP	0.7	1.7	3.5	2.0	**1.9**
GST	1.8	2.2	2.3	2.9	**2.2**	GST	1.0	2.3	2.3	1.5	**1.8**

Notes: $\bar{x}$* indicates the weighted average according to the weights in Table 2. Source: Own elaboration.

Considering these results, as well as the insights derived from the plenary discussions held during the workshop, the measures selected for further socioeconomic assessment were the six highest-rated: irrigation modernization, conversion from rainfed to irrigated farming, crop substitution, variety change, crop rotation, and no-till farming. Additionally, cover crops and extensive grazing were included due to the strong interest generated by the eco-schemes of the Common Agricultural Policy (2023-2027) in the debates among local stakeholders during the workshop.

3.2. Socioeconomic assessment of prioritized adaptation measures

Figure 2 presents the results of the impact of the eight adaptive measures on each of the four thematic blocks detailed in Section 2.3 (aspects related to farm income; environmental benefits, and climatic and biological resilience; aspects related to farm costs; and barriers to the implementation of adaptive measures). In each case, the measures are ordered from highest to lowest impact within the corresponding block. These results show that measures related to the conversion of rainfed land to irrigation (IRR) and the modernization of irrigation systems (MOD) exhibit some of the highest values for impact on aspects related to income, with average scores close to 3, as well as intermediate-to-high values for environmental benefits, and climatic and biological resilience, with average scores above 2.5. However, these perceived benefits are largely outweighed by their impact on farm costs (IRR: 3.9; MOD: 3.4) and by the difficulties perceived by farmers in implementing them in the SCAB (MOD: 3.9; IRR: 3.9), with them clearly leading both rankings above the rest of the measures.

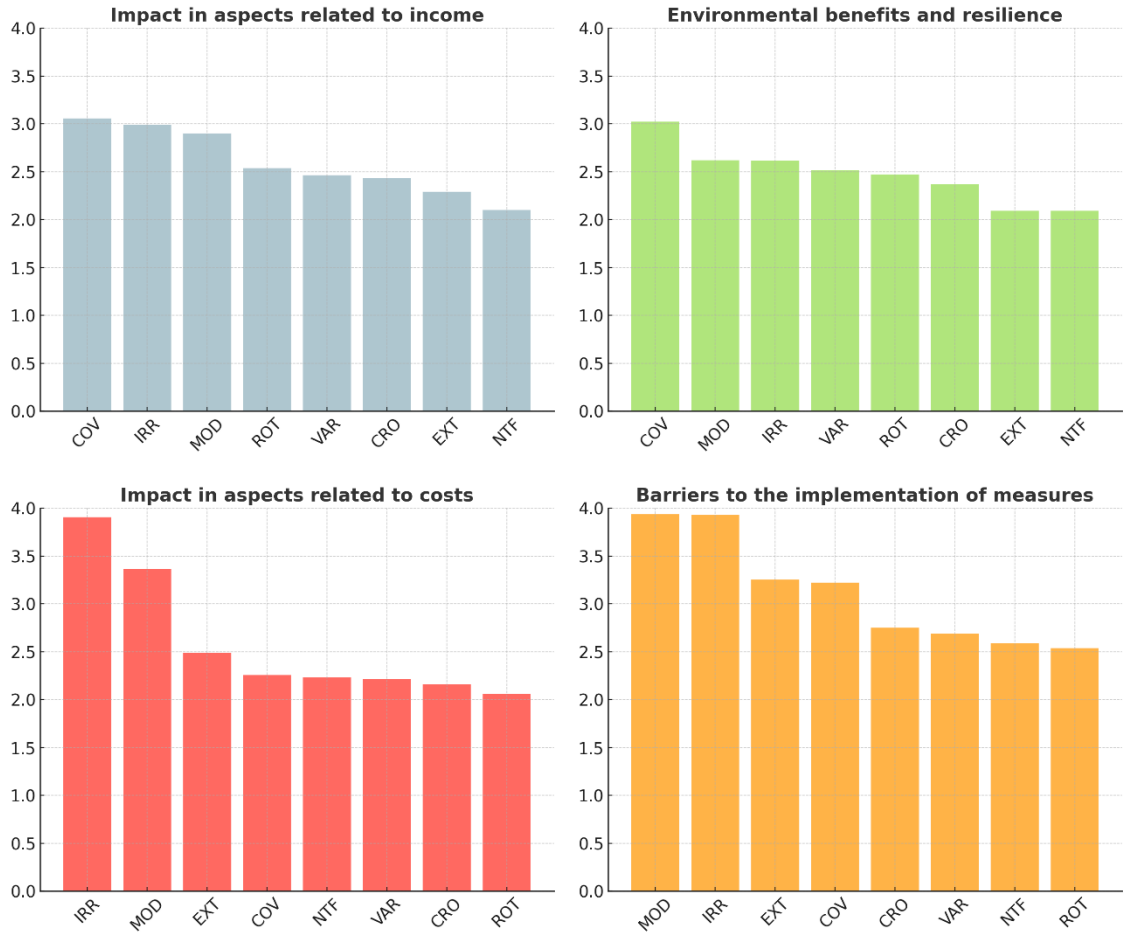

Figure 2. Perceived impact of adaptive measures on farm income, environmental benefits and resilience, farm costs, and implementation barriers.

In the case of measures related to variety change (VAR) and crop change (CRO), both show intermediate values, around 2.5, for the two blocks of positive impacts (impact on aspects related to income, and environmental benefits, and climatic and biological resilience). Regarding the blocks of negative impacts, both exhibit low values (slightly above 2) for impact on farm costs, and intermediate values (slightly above 2.5) for barriers to the implementation of adaptive measures.

Regarding the four CAP eco-schemes considered in the analysis, the good performance of cover crops for woody crops (COV) stands out, particularly in terms of impact on aspects related to income and environmental benefits, and climatic and biological resilience, leading both rankings with values slightly above 3. These positive results in the blocks of positive impacts are accompanied by intermediate values (slightly above 2) for impact on farm costs, and intermediate-to-high values (slightly above 3) for perceived barriers to their implementation. Similarly, crop rotation with soil-improving species (ROT) shows good results for the positive impact blocks (although lower than those of COV, IRR, and MOD), with values around 2.5 in both cases. These are complemented by the lowest values among all measures for both impact on farm costs (ROT: 2.1) and perceived barriers to implementation (ROT: 2.5).

On the other hand, the other two eco-schemes, no-till farming (NTF) and extensive grazing (EXT), show the worst results in terms of impact on aspects related to income and environmental benefits, and climatic and biological resilience, with values slightly above 2 in

both cases. Moreover, EXT exhibits intermediate-to-high values (just behind IRR and MOD) for the negative impact blocks, while NTF shows intermediate-to-low values for these blocks.

To condense all this information and facilitate the interpretation of which measures might be more feasible and beneficial to implement in the SCAB region, Figure 3 presents the net balance, obtained by subtracting the results of each measure in the negative impact blocks from their results in the positive impact blocks.

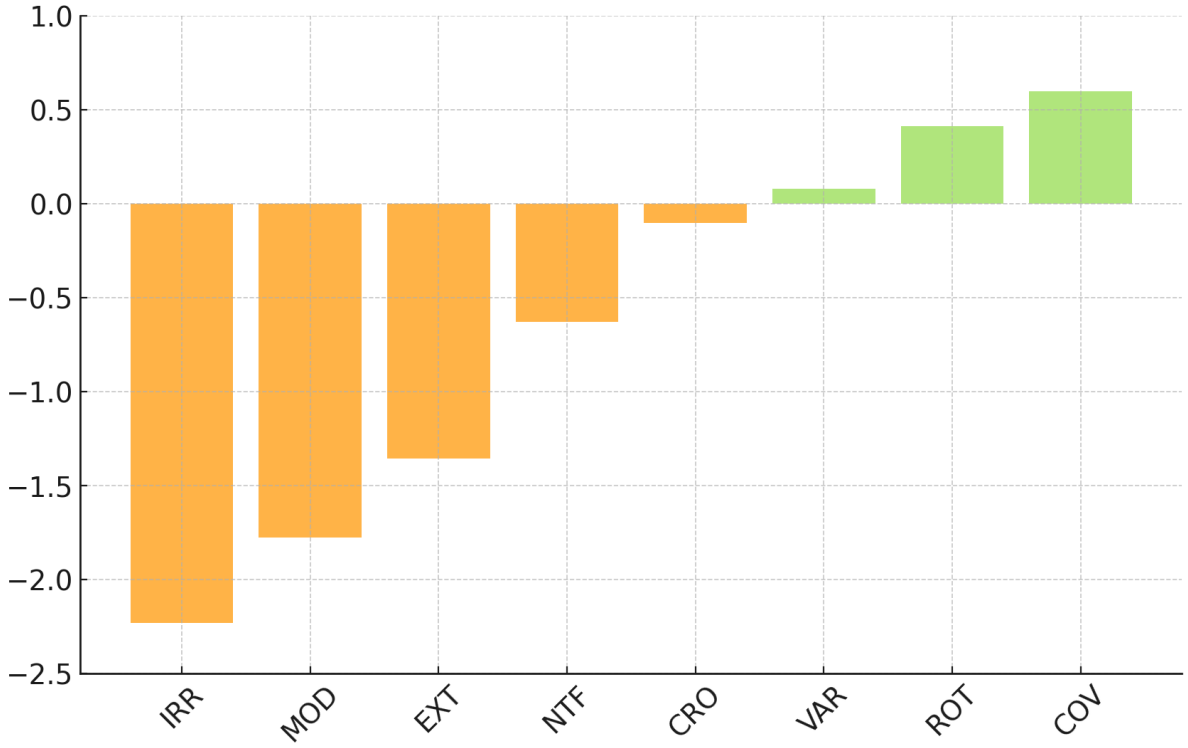

Figure 3. Net balance of positive (aspects related to income, and environmental benefits and resilience) and negative (aspects related to costs, and barriers to the implementation of measures) impacts.

The results of this net balance (Figure 3) highlight that the least feasible adaptive measures to implement in the SCAB region are the conversion of rainfed land to irrigation (net balance of -2.2) and the modernization of irrigation systems (net balance of -1.8). This is due to their poor performance in terms of costs and barriers to implementation, despite the considerable benefits attributed to them by farmers in the region.

A similar, though less pronounced, pattern is observed for two of the CAP eco-schemes: extensive grazing (net balance of -1.4) and no-till farming (net balance of -0.6). However, in this case, the main reason is the limited benefits perceived by farmers for these measures.

At the opposite end of the net balance spectrum, we find the other two CAP eco-schemes: crop rotation with soil-improving species (ROT) and cover crops for woody crops (COV), which present a net balance of 0.4 and 0.6, respectively. This positions them as the two most feasible measures to implement in the study region for adapting to the effects of climate change (COV due to its higher perceived benefits and ROT due to its lower perceived disadvantages), according to the vision of the SCAB farmers.

Finally, in the neutral zone of the balance, we find measures related to crop (CRO) or variety (VAR) changes for more resilient species. In both cases, the results indicate a balanced trade-off between perceived benefits and drawbacks, with a net balance of -0.1 for CRO and 0.1 for VAR.

To further explore the reasons behind the results of each measure, Figure 4 presents the average impact of each measure on each item within each block. Building on the classification derived from the net balance results (Figure 3), Figure 4 shows how irrigation-related measures (IRR and MOD) exhibit the most challenging values for nearly all items within the negative impact blocks. Notably, they stand out in terms of administrative obstacles to implementation, the need for initial investment, water requirements, energy costs, and the need for technical training, among others. As previously mentioned, these measures were also attributed significant benefits, mainly related to the expected increase in crop yields, agricultural product quality, drought resilience, and water savings (in the case of MOD).

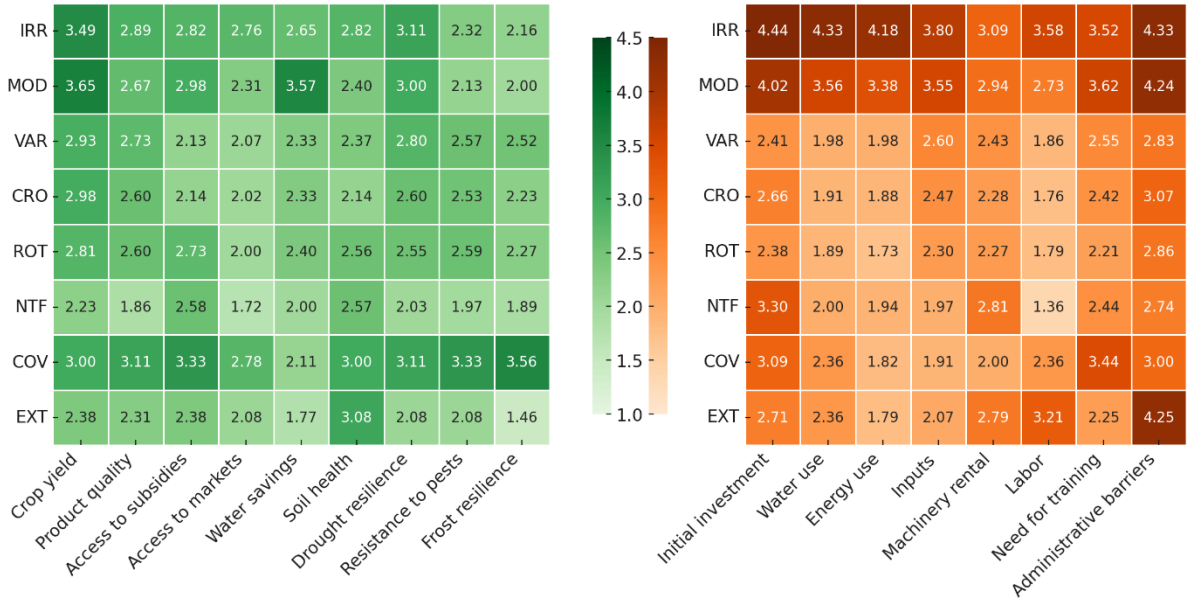

Figure 4. Heatmap of average impact per item and measure. The items on the left refer to the positive impact blocks (the greener, the better), while the items on the right refer to the negative impact blocks (the more orange, the worse).

For the two least feasible eco-schemes to implement according to the net balance results (EXT and NTF), Figure 4 reveals distinct limiting factors for each. In the case of extensive grazing (EXT), the most restrictive factors are related to administrative obstacles to implementation, the need for labor and machinery, as well as investment and training requirements. On the other hand, for no-till farming (NTF), the most critical issues are related to initial investment, the need for machinery, and the need for training, likely linked to the requirement of a specific no-till seeder for implementing this measure.

For the other two eco-schemes, ROT and COV, which had the best net balance among all measures (Figure 3), the results in Figure 4 show that cover crops (COV) exhibit a notable performance across nearly all items. This is particularly evident in aspects related to soil health improvement and resilience to climatic and biological factors, such as frost resistance, which plays a key role in the SCAB region. Regarding the challenges associated with this measure, the most notable ones are the need for technical training and initial investment. Meanwhile, crop rotation (ROT) stands out for its consistently low values across nearly all negative impact items, combined with generally good results in the positive impact items, particularly in terms of crop yield improvement.

After analyzing the results of the socioeconomic impact of the potential implementation of these measures in the SCAB, Figure 5 presents the level of importance that the interviewed farmers assign to different types of incentives, depending on the adaptive measure considered.

Figure 5. Importance of incentives by adaptive measure, expressed as the percentage of farmers who identified that incentive as relevant within each measure.

Based on these results, the incentives that SCAB farmers identified as the most relevant are technical advisory, followed by fairer allocation of CAP aid and access to subsidies. Technical advisory stands out clearly above the rest, particularly in the case of variety and crop change measures, as well as for all eco-schemes except extensive grazing. Regarding the fairer allocation of CAP aid, its importance is justified not only by the presence of eco-schemes among the adaptation measures analyzed but also by the strong mobilization within the agricultural community in the study area, actively demanding a fairer redistribution of CAP subsidies. Finally, access to subsidies is widely demanded among farmers, while financial advisory and access to low-interest loans are particularly sought after for irrigation-related measures, which aligns with the high investment needs previously identified for these measures.

When considering the results of this study, it is important to note their provisional nature, particularly those related to the socioeconomic assessment of prioritized adaptation measures. This is due to the fact that the full set of planned surveys has not yet been completed and that some of the measures analyzed, such as cover crops and extensive grazing, have a lower response rate among farmers (largely because woody crops and livestock farming are less prevalent in the SCAB region).

4. Conclusion

This study assesses the feasibility and socioeconomic impact of eight prioritized adaptation measures in the SCAB region, providing insights into their potential benefits and challenges. The findings highlight significant differences in the perceived effectiveness, costs, and implementation barriers of these measures, shaping their overall feasibility for adaptation to climate change.

The conversion of rainfed land to irrigation, and the modernization of irrigation systems were identified as the least feasible measures, despite their high potential to enhance farm income and drought resilience. The main limiting factors for these measures are the high initial investment requirements, water requirements, and significant administrative barriers, which make their implementation in the SCAB particularly challenging. On the contrary, the most feasible measures, according to farmers' perceptions, are crop rotation with soil-improving species, and cover crops for woody crops, which achieved the highest net balance scores. These CAP eco-schemes are characterized by great to moderate benefits in terms of farm income, environmental benefits and resilience, coupled with lower implementation costs and fewer barriers compared to other strategies. Measures such as crop substitution and variety change present a balanced trade-off between benefits and limitations, making them viable options for adaptation under specific conditions. Meanwhile, extensive grazing and no-till farming, despite their alignment with CAP eco-schemes, were found to be less attractive due to limited perceived benefits and relatively high implementation difficulties.

The analysis of incentive preferences reveals that farmers strongly favor technical advisory services, followed by a fairer allocation of CAP subsidies and improved access to financial support. These findings emphasize the need for tailored policy interventions and financial mechanisms to facilitate the adoption of this kind of measures.

A key strength of this study is its participatory approach, which integrates the perspectives of local actors, including farmers, policymakers, agricultural engineering companies, environmentalists, and experts. This bottom-up validation ensures that the measures assessed are relevant to local realities and that the recommendations align with practical on-the-ground challenges. The active involvement of stakeholders not only enhances the credibility of the findings but also fosters a sense of ownership among local communities, increasing the likelihood of successful implementation.

Overall, this study provides valuable input for agricultural policymakers and stakeholders, offering a farmer-centered perspective on adaptation feasibility. By addressing economic, environmental, and technical challenges, and by leveraging the expertise and validation of local actors, policymakers can design more effective and targeted support strategies to foster climate resilience in Mediterranean agriculture.

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