149. Smart irrigation in Mediterranean countries: Adoption and policy challenges

P. Toscano[1,*], I. Borra-Serrano[2], J.M. Peña[2], K. Aberkani[3], R. Lahlali[4], B. Ploteau[5], B. Tisseyre[5], J.J. Sousa[6], R. Morais[6], A.I. de Castro[7], R. Dainelli[1], S.F. Di Gennaro[1] and A. Matese[1]

[1] *Institute of BioEconomy, National Research Council (CNR-IBE), Florence, Italy; * piero.toscano@ibe.cnr.it*

[2] *Institute of Agricultural Sciences (ICA), CSIC; Madrid, Spain*

[3] *University Mohammed First, Multidisciplinary Faculty of Nador, Nador, Morocco*

[4] *Department of plant protection and environment, Ecole Nationale d'Agriculture de Meknès, Meknès, Morocco*

[5] *ITAP, Université Montpellier, INRAE, Institut Agro, Montpellier, France*

[6] *Engineering Department, University of Trás-os-Montes e Alto Douro, Portugal*

[7] *National Agricultural and Food Research and Technology Institute (INIA), CSIC, Madrid, Spain*

Abstract

Water scarcity challenges Mediterranean agriculture, where irrigation consumes most water resources. Within the DATI project, 238 farmers and 52 policymakers across Spain, Portugal, Morocco, Italy, and France were surveyed on irrigation practices, smart technology adoption, and barriers to implementation. Farmers identified water scarcity, initial investment costs, limited awareness, and inadequate training as key challenges, while policymakers emphasized the need for improved inter-agency coordination and enhanced infrastructure. Nevertheless, farmers expressed strong interest in adopting smart irrigation, emphasizing the need for targeted policies, financial incentives, and comprehensive training. This study offers actionable insights to enhance stakeholder collaboration and advance sustainable irrigation.

Keywords: barriers, digital farming, farmers, irrigation, policymakers, readiness, survey

Introduction

The Mediterranean region faces significant challenges such as water scarcity and extreme climatic events, making it a critical area for implementing effective water management and climate adaptation strategies. Agriculture is the largest consumer of water in the region, with some areas using up to 80% of available water, significantly exceeding the 44% average in other parts of Europe and the global average of 75% (Crovella *et al.*, 2022). While irrigated agriculture sustains rural livelihoods by providing jobs and income, its environmental sustainability is increasingly questioned due to water scarcity and climate change. Rising temperatures and shifting rainfall patterns are expected to intensify pressures on crop productivity and water resources. Irrigation remains essential for maintaining yields and food security amid these challenges (Daccache *et al.*, 2014). However, higher irrigation demands may raise energy use and greenhouse gas emissions, potentially conflicting with climate mitigation goals (Mushtaq *et al.*, 2013). Smart irrigation technologies, such as precision irrigation and real-time monitoring tools, offer a promising solution. By optimizing water use, these technologies conserve resources, reduce waste, and mitigate environmental impacts, making them essential for sustainable agriculture (Kakkavou *et al.*, 2024). Despite their potential, the adoption remains limited due to economic, informational, and infrastructural barriers. To investigate these challenges, this study conducted a comprehensive survey across five countries France, Italy, Morocco, Portugal, and Spain. The survey explored the adoption of precision irrigation technologies by farmers and the awareness of policymakers regarding these innovations and the barriers to their implementation. A key objective was to assess the alignment - or disconnection – between the needs and perceptions of farmers, the policies and support systems available to design a possible strategy to facilitate adoption. This research builds on prior studies that have examined the adoption of precision irrigation in specific contexts (Kakkavou *et al.*, 2024; Kernecker *et al.*, 2020). However, it is the first to analyze farmers and policymakers simultaneously, offering a holistic perspective on the interplay between technological readiness, policy frameworks, and practical barriers. By addressing these issues, the study aims to provide actionable insights to bridge gaps and foster more effective implementation of precision irrigation technologies in the Mediterranean.

Materials and methods

Survey design and theoretical framework for farmer adoption and policy challenges

The survey was developed collaboratively by DATI (Digital Agriculture Technologies for Irrigation Efficiency) with input from social and behavioural scientists (DATI, 2024). Its goal was to examine factors influencing farmers' adoption of precision irrigation and assess policymakers' awareness of adoption barriers. The framework focused on five key dimensions: (1) farmers' perceived ability to adopt and use these tools effectively, (2) sustainability and environmental awareness in decision-making, (3) perceived economic benefits, (4) compatibility with existing agricultural practices, and (5) concerns about risks linked to new technologies. A similar framework had been successfully applied by Kakkavou *et al.* (2024) in studying olive and cotton farming in Greece. For policymakers, this framework was adapted to assess their understanding of farmers' challenges and their perspectives on policy measures to support the transition to precision irrigation. To ensure the survey's reliability and relevance, a pilot phase was conducted with 15 farmers and 8 policymakers from Italy and Morocco. The policymakers represented diverse roles and responsibilities, including local government officials, regional agricultural advisors, and national policy planners. These participants tested the draft questionnaire and provided critical feedback on question reliability, sequencing, and length. Their input, excluded from the final analysis, improved survey clarity and effectiveness. The final questionnaire included both open- and closed-ended questions, with key questions placed at the beginning to ensure clear and relevant responses. Closed-ended questions followed a five-point Likert scale, ranging from "strongly disagree" (0) to "totally agree" (4), with verbally labelled responses to reduce bias (Wright, 1975). The survey was translated into Arabic, French, Italian, Spanish, and Portuguese and offered in print and digital formats for accessibility. To ensure meaningful participation, strict eligibility criteria were applied. Farmers were required to be over 18 years old, actively engaged in farming for at least two years, and proficient in one of the survey languages. Policymakers were required to have at least two years of experience in policymaking and proficiency in one of the survey languages. The surveys were conducted during the summer of 2023 as part of the DATI project's living lab events organized across five participating countries. These events provided a platform for direct engagement with stakeholders, ensuring that the insights captured reflected real-world conditions faced by farmers and policymakers. A total of 238 farmers responded to 44 questions covering sociodemographic characteristics, education, and irrigation practices. The survey focused on their current water consumption, irrigation systems, and overall experiences with water management. Additionally, it examined farmers' readiness to adopt smart irrigation technologies, their familiarity with these tools, adoption rates, and any training received in their use. Farmers were also asked about their willingness to invest in such technologies, their awareness of financial incentives or subsidies, and their interest in sharing knowledge with peers through demo events or collaborative activities. Simultaneously, 52 policymakers completed a questionnaire of 31 questions assessing their knowledge of smart irrigation technologies, understanding of farmers' adoption barriers, and awareness of existing policy frameworks. The survey explored their research into challenges faced by farmers, inter-agency coordination efforts, and examples of successful pilot projects. Policymakers were invited to propose strategies to address the barriers identified, highlighting the role of education and research in promoting digital irrigation technologies.

Data analysis and study area

The survey was conducted in five regions across DATI project countries, engaging farmers and policymakers at local, regional, and national levels. Each region was selected for its agricultural characteristics and relevance to the study. In Morocco, the survey targeted the northeastern regions of Driouch and Nador, where arable crops, vegetables, and orchards predominate. In France, it focused on Languedoc-Roussillon, a southern region dominated by grapevines. The Spanish survey covered the southeastern wine-growing area of Madrid. In Portugal, the Douro region, renowned for its grapevines, was selected. In Italy, the focus was the Grosseto district in Tuscany, a diverse agricultural area producing arable crops, vegetables, olives, and grapevines. This geographical and agricultural diversity provided a solid basis for understanding challenges and perceptions regarding digital irrigation adoption in different Mediterranean contexts. Responses to open-ended questions were categorized and analyzed. Data normalization was conducted within each country to enable a cohesive overview of the findings. Quantitative data were processed using Microsoft Excel, while qualitative responses were analyzed with VOSviewer (2024) (van Eck and Waltman, 2010). This software facilitated clustering analysis, identifying relationships between keywords and recurring themes in survey responses. The methodology integrated qualitative and quantitative data to provide a holistic view of adoption challenges and policy implications. Keyword clustering from open-ended responses revealed patterns in farmers' concerns, such as water scarcity, economic constraints, and technological barriers, as well as policymakers' perspectives on infrastructure and coordination challenges. This approach highlighted regional nuances while identifying cross-cutting issues relevant to the Mediterranean region.

Results and discussion

Adoption and policy challenges

The survey found that 63.8% of farmers used some form of irrigation technology, though adoption varied across countries. Spain, France, Italy, and Portugal reported rates between 64.7% and 75.9%, while Morocco lagged at 32.2%. Among these, 30% relied on technical advisors, 20% used decision support systems, and 50% employed self-developed methods. The latter group integrated various data sources, including weather station data (20.7%), remote sensing (11.5%), soil sensors (14.6%), plant sensors (10.8%), weather forecasts (28.5%), and tool combinations (13.9%). Overall, only 25.9% of farmers actively used digital irrigation technologies, a figure 20% higher than adoption rates previously reported for olive and cotton farms in Greece (Kakkavou *et al.*, 2024). 64.6% of farmers were willing to invest in digital irrigation technologies, with the highest percentage in Italy (100%) and the lowest in France (42.8%). In Morocco, 41% of unwilling farmers cited land tenure as a key barrier, as they operate under short-term rental agreements. Among those ready to invest, 66.3% were seriously concerned about high initial costs, a concern strongest in Italy (100%) and least significant in Portugal (44.9%). Cost apprehension was closely linked to awareness of financial incentives or subsidies for adoption. On average, only 48.6% of farmers knew about such support, with awareness ranging from just 12% in Italy to 65% in Portugal. Similar levels were reported in France and Morocco (43–44%) and 23.5% in Spain. These disparities highlighted structural issues at regional and national levels, independent of farmers' demographics or farm size (Tables 2–3), differing from previous findings (Wainaina *et al.*, 2016; Hu *et al.*, 2022). In France, Morocco and Spain 70% of farmers reported a lack of information and training on digital irrigation systems, compared to 60.4% in Italy and Portugal, where farmers had received such support. Of the farmers who had access to training, 41.1% participated in seminars or workshops organized by private entities. Another significant issue highlighted by the survey was the lack of information about successful cases of digital irrigation in real farming conditions. Over half of the farmers surveyed (56.3%) stated they were unaware of any successful examples, with the highest percentage in Italy (84.6%), followed by Morocco, France, and Spain (57.4–67.1%), and the lowest in Portugal (35.4%). This gap is critical, as research has demonstrated that observing and experiencing the practical application of such technologies on fellow farmers' plots significantly increases the likelihood of adoption (Blasch *et al.*, 2022). Farmers reported moderate confidence (2.4 out of 4) in their ability to manage and maintain digital irrigation systems. They identified key requirements for adoption, including information on system reliability (3.8 out of 4), actual costs (3.6), management support (3.3), training (3.1), and subsidies (3.0). Additional needs included easy-to-use systems (2.9) and assistance in selecting the most suitable solutions (2.6) based on soil, climate, water availability, and crops. Policymakers (see Tables 4–5), using the same scoring system, identified economic barriers as the most critical obstacle to adoption (3.9), followed by the need for training and information (3.1), insufficient water infrastructure (3.0), lack of knowledge (2.9), cultural resistance to innovation (2.8), and prior failures with technology adoption (2.0). While some responses from farmers and policy makers align, the survey revealed gaps in policymakers' awareness of farmers' challenges. Only 61.1% of policymakers reported familiarity with digital agriculture technologies, and 49.8% rated inter-agency coordination as very poor. Furthermore, 92% of policymakers believed that farmers' awareness of the benefits of digital irrigation was low or moderate, with just 26.1% having conducted research on barriers to adoption. Only 58.5% had experience with successful precision irrigation case studies or pilot projects. Policymakers acknowledged the critical role of research in promoting digital irrigation (89.2%) and highlighted the need to address concerns and risks associated with widespread adoption (52.7%). Encouragingly, 75.6% of policymakers indicated there were no legal or regulatory barriers preventing adoption. Farmers also valued research highly: 80.6% were willing to share data for studies evaluating smart irrigation efficiency, and 71.5% expressed interest in participating in future research projects. Notably, 95.4% of these farmers were willing to host research activities on their farms, demonstrating a strong commitment to collaborative efforts for advancing digital irrigation technologies. These findings align with Pires *et al* (2024), who highlighted that farmers are generally receptive to collaborating with universities on on-farm research. Moreover, farmers were found to be 40% more likely to adopt practices validated by on-farm research compared to those derived from off-site studies.

Sample consciousness and characteristics

Most surveyed farmers reported significant benefits from digital irrigation technologies (Table 1). Specifically, 75.7% agreed they increase yield, 78.9% believed they reduce water costs, 53.5% highlighted lower electricity costs, 81.3% emphasized water conservation, and 83.9% recognized improved product quality. Regarding the question, "What percentage of your farming budget is allocated to irrigation?", farmers reported an average allocation of 20% in Morocco, 5% in Italy, 11% in France, 12% in Portugal, and 15% in Spain. Notably, 21% had no irrigation costs, mainly due to free water access or solar-powered systems. Despite these benefits, concerns over water availability and quality remain paramount.

In response to the question, "What are the primary challenges you encounter in managing water resources on your farm?", farmers' answers revealed four distinct clusters (Figure 1): (i) Climate change, extreme events, labour market challenges, and water quality; (ii) Costs, drought, equipment shortages, and water salinity; (iii) Crop failure and water scarcity; (iv) Water distribution timing and access. Farmers expressed serious concerns about the impacts of climate change and extreme events such as drought, which are negatively affecting both water availability and quality, including increasing water salinity. Additionally, costs, labour shortages, and inefficiencies in water distribution emerged as key challenges. Despite efforts to mitigate response bias through structured survey questions and diverse sampling, some participants may have provided responses they believed aligned with organizer expectations. Additionally, selection bias could arise, as participants were drawn from living lab events rather than randomly selected, potentially limiting broader representativeness. These factors should be considered when interpreting results.

Table 1**.** Farmers' perceptions of the benefits of digital irrigation technologies, based on a 5-point Likert scale.

	Totally agree	Somewhat agree	Without opinion	Mostly disagree	Strongly disagree
Increase the yield	58.3	17.4	14.7	7.3	2.3
Reduce water costs	43.6	25.3	17.3	8.0	5.8
Reduce fuel costs	31.1	16.9	35.1	10.8	6.1
Reduce electricity costs	35.2	18.3	30.3	9.9	6.3
Preserve water resources	53.5	27.8	12.5	3.5	2.8
Manage harvest quality	56.4	27.5	11.4	2.7	2.0

Data presented as percentages.

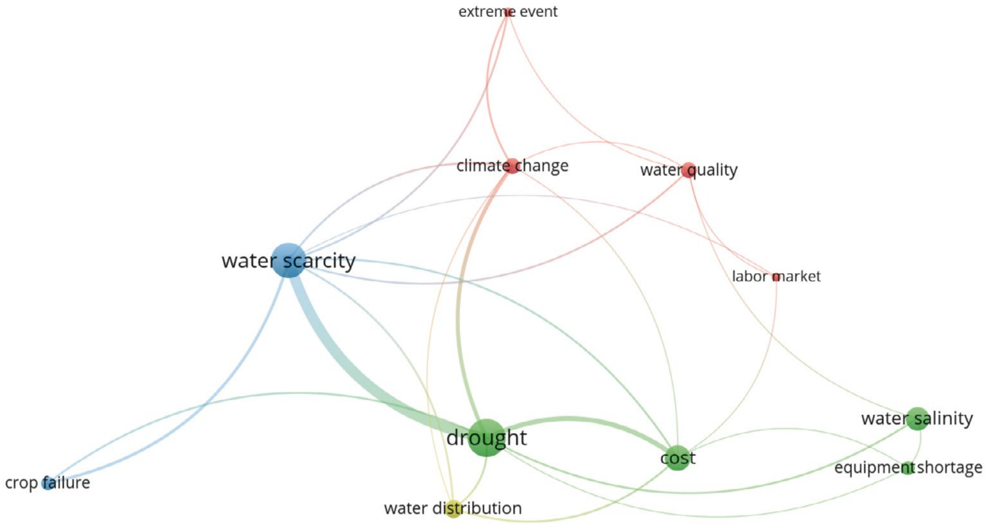

Figure 1. Visualization of keywords clusters based on the farmers answers to "What are the primary challenges you encounter in managing water resources on your farm?"

Table 2. Socio-demographic characteristics of farmers across the five Mediterranean countries studied.

	Age			Sex		Google maps user	
	18-35	36-60	>60	F	M	Yes	No
Morocco	30.2	13.8	56.0	98.3	1.7	37.8	62.2
Italy	0.0	75.3	24.7	75.3	24.7	100.0	0.0
France	0.0	57.1	42.9	85.7	14.3	78.6	21.4
Portugal	15.6	31.2	53.2	65.8	34.2	87.0	13.0
Spain	23.5	52.9	23.5	76.5	23.5	100.0	0.0

Data presented as percentages.

Table 3. Farm characteristics and educational attainment of farmers in the study regions.

	Farm			Education			
	Avg. size (ha)	Irrigated (%)	Smallholders (%)	Elementary or less	Junior High	Senior High	Bachelor or higher
Morocco	21.45	74.8	23.3	28.8	28.8	14.4	27.9
Italy	207.4	28.6	0.0	0.0	0.0	62.5	37.5
France	36.7	49.4	7.1	7.1	0.0	35.7	57.1
Portugal	15.4	39.0	14.9	19.0	26.6	29.1	25.3
Spain	249	59.0	13.0	0.0	0.0	0.0	100.0

Data presented as percentages.

Table 4. Socio-demographic characteristics and educational attainment of policymakers in the study regions.

	Age			Sex		Education	
	18–35	36–60	>60	F	M	Senior High	Bachelor or higher
Morocco	66.7	33.3	0.0	80.0	20.0	13.3	86.7
Italy	20.0	66.7	13.3	73.3	26.7	26.7	73.3
France	22.2	44.4	33.4	88.9	11.1	11.1	88.9
Portugal	0.0	75.0	25.0	50.0	50.0	25.0	75.0
Spain	11.1	44.4	44.5	77.8	22.2	0.0	100.0

Data presented as percentages.

Table 5. Professional roles and organizational affiliations of policymakers in the study regions.

	Organization			Position		Service	
	National/ International	Regional	Local	Elected	Employee	Agriculture	Other
Morocco	60.0	33.3	6.7	6.7	93.3	85.7	14.3
Italy	6.7	40.0	53.3	14.3	85.7	80.0	20.0
France	77.8	22.2	0.0	11.1	88.9	100.0	0.0
Portugal	25.0	75.0	0.0	0.0	100.0	100.0	0.0
Spain	77.8	22.2	0.0	0.0	100.0	77.8	22.2

Data presented as percentages.

Conclusions

Farmers highlighted challenges related to the complexity, costs, and reliability of digital irrigation systems, stressing the need for training and maintenance support. Climate change and extreme weather, particularly their impact on water availability and quality, emerged as critical factors for irrigation planning. These concerns were shared across diverse farming contexts, regardless of farm size or demographics. A clear disconnect between farmers and policymakers was evident. Farmers emphasized the need for financial incentives, practical demonstrations, and training, while policymakers focused on infrastructure and coordination. Limited engagement by policymakers with on-the-ground challenges and pilot projects highlights a critical gap that must be addressed to align policy frameworks with farmers' realities. Despite these barriers, farmers showed a strong willingness to collaborate on research and adopt new technologies when adequately supported. This underscores the need for participatory approaches involving all stakeholders to address technical and economic challenges effectively. Bridging these gaps through targeted policies, improved training, and showcasing successful examples can accelerate the adoption of digital irrigation technologies, enhancing the sustainability and resilience of Mediterranean agriculture.

Acknowledgements

DATI—Digital Agriculture Technologies for Irrigation efficiency supported by the EU through the PRIMA Programme and MIUR (ID:1585/2020).

References

Blasch, J., van der Kroon, B., van Beukering, P., Munster, R., Fabiani, S., Nino, P., & Vanino, S. (2022). Farmer preferences for adopting precision farming technologies: a case study from Italy. *European Review of Agricultural Economics, 49(1), 33–81*. https://doi.org/10.1093/erae/jbaa031

Crovella, T., Paiano, A., & Lagioia, G. (2022). A meso-level water use assessment in the Mediterranean agriculture. Multiple applications of water footprint for some raditional crops. Journal of Cleaner Production, 330, 129886. https://doi.org/10.1016/j.jclepro.2021.129886

Daccache, A., Ciurana, J.S., Rodriguez Diaz, J.A., & Knox, J.W. (2014). Water and energy footprint of irrigated agriculture in the Mediterranean region. Environmental Research Letters, 9, 124014. https://doi.org/10.1088/1748-9326/9/12/124014

DATI (2024). Website. Available online at https://datiproject.eu/ (accessed 22 November 2024).

Hu, Y., Li, B., Zhang, Z., & Wang, J., (2022). Farm size and agricultural technology progress: Evidence from China. Journal of Rural Studies, 93, 417–429. https://doi.org/10.1016/j.jrurstud.2019.01.009

Kakkavou, K., Gemtou, M., & Fountas, S. (2024). Drivers and barriers to the adoption of precision irrigation technologies in olive and cotton farming – Lessons from Messenia and Thessaly regions in Greece. Smart Agricultural Technology, 7, 100401. https://doi.org/10.1016/j.atech.2024.100401

Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., & Borges, F. (2020). Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe. Precision Agriculture, 21, 34–50 https://doi.org/10.1007/s11119-019-09651-z

Mushtaq, S., Maraseni, T.N., & Reardon-Smith, K. (2013). Climate change and water security: Estimating the greenhouse gas costs of achieving water security through investments in modern irrigation technology. Agricultural Systems, 117, 78–89. https://doi.org/10.1016/j.agsy.2012.12.009

Pires, C.B., Krupek, F.S., Carmona, G.I., Ortez, O.A., Thompson, L., Quinn, D.J., …, & Ciuampitti, I.A. (2024). Perspective of US farmers on collaborative on-farm agronomic research. Agronomy Journal, 116, 1590–1602. https://doi.org/10.1002/agj2.21560

van Eck, N.J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84, 523–538. https://doi.org/10.1007/s11192-009-0146-3

Vosviewer (2024). Visualizing scientific landscapes. Available online at https://www.vosviewer.com/ (accessed 26 October 2024).

Wainaina, P., Tongruksawattana, S., & Qaim, M. (2016). Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. Agricultural Economics, 47, 351–362. https://doi.org/10.1111/agec.12235

Wright, J.D. (1975). Does acquiescence bias the "Index of Political Efficacy?" The Public Opinion Quarterly, 39(2), 219–226.