# Stakeholder's Perspective on Smart Farming Robotic Solutions

George Papadopoulos[a,d], Maria-Zoi Papantonatou[a,d], Havva Uyar[b], Konstantinos Nychas[a], Vasilis Psiroukis[a], Aikaterini Kasimati[a], Ard Nieuwenhuizen[c], Frits Van Evert[c], Spyros Fountas[a]

[a] *Laboratory of Agricultural Engineering, Department of Natural Resources Management & Agricultural Engineering, School of Environment and Agricultural Engineering, Agricultural University of Athens, 11855 Athens, Greece*
[b] *Research and Development Department, SingularLogic, 14564 Athens, Greece*
[c] *Agrosystems Research, Wageningen University & Research, Droevendaalsesteeg 1, 6708 PB Wageningen, The Netherlands*
[d] *Faculty of Crop Science, Agricultural University of Athens, 11855 Athens, Greece*

**Abstract**

This study examines agricultural stakeholders' perceptions of robotic farming technologies through feedback collection and analysis in the context of Robs4Crops project, employing a mixed-method approach that combines quantitative and qualitative questionnaires. Feedback was gathered from 104 participants, including farmers, researchers, tech providers, policy makers, and others in demonstrations across France, Greece, Spain, and the Netherlands, along with 54 agricultural students engaged in demonstrations at the Agricultural University of Athens. The findings highlight the potential of robotic solutions in agriculture. Agricultural stakeholders highlighted key benefits such as labour reduction, cost efficiency, and improved productivity, alongside challenges like high initial costs, technical skill gaps, and scepticism, particularly among older generations. Practical, hands-on demonstrations emerged as a pivotal factor in changing perceptions and fostering acceptance, with stakeholders advocating for user-friendly tools, financial incentives, and collaborative farming models. Agricultural students, as future practitioners, showed limited prior familiarity with technologies like Digital Twins and Farming Controller for remote monitoring of robots but demonstrated strong engagement and learning during demonstrations. Students valued automation, resource efficiency, and reduced chemical use as key benefits, while also stressed the importance of interactive learning experiences such as task simulations and real-world applications to bridge knowledge gaps effectively. The findings underscore the importance of tailored strategies to engage both current and future stakeholders. Addressing barriers through targeted education, financial support, and inclusive outreach can facilitate the integration of robotic solutions into sustainable agriculture. By fostering collaboration among farmers, students, researchers, and policymakers, this study outlines a roadmap for leveraging robotic innovations to advance agricultural efficiency, sustainability, and resilience.

**Keywords**: Robotic Agriculture; Stakeholder Engagement; Smart Farming Technologies; Adoption Barriers and Solutions; Interactive Demonstrations

## 1. Introduction

Global agriculture is undergoing a paradigm shift driven by the need to ensure food security, combat labour shortages, and promote sustainable farming practices. Smart farming technologies, particularly agricultural robotics, have emerged as transformative tools in addressing these challenges (Papadopoulos et al., 2024). These robotic systems automate labour-intensive processes such as planting, weeding, and harvesting, offering a way to alleviate the dependency on manual labour while significantly improving productivity and operational efficiency (Shamshiri et al., 2018; Balafoutis et al., 2017).

The urgency of these innovations is underscored by the acute labour shortages plaguing the sector. Agricultural labour is in decline globally due to rural depopulation, an ageing workforce, and a lack of interest from younger generations in pursuing agricultural careers. Robotic technologies provide a potential solution by automating repetitive tasks, enabling 24/7 operation, and allowing farmers to redirect human resources to more strategic areas of farm management. These systems also enhance sustainability by optimising the use of resources such as water, fertiliser, and pesticides, reducing waste, and minimising environmental impact (Pedersen et al., 2020).

However, the integration of robotic solutions into real-world agricultural settings faces significant hurdles. The high cost of these systems is a major barrier, particularly for small- to medium-sized farms that operate with limited budgets (Wolfert et al., 2017). Technical challenges, including the need for advanced knowledge to operate and maintain robots, further complicate their adoption. Infrastructure issues, such as the lack of reliable connectivity in rural areas, exacerbate these difficulties, particularly in regions where digital infrastructure remains underdeveloped. Additionally, cultural resistance to change, coupled with scepticism about the reliability and long-term benefits of robotic systems, limits the willingness of many farmers to adopt these innovations (Mouzakitis et al., 2021).

A smooth transition from traditional farming practices to smart, data-driven agriculture necessitates not only advancements in innovative technologies but also the implementation of comprehensive adoption strategies. Engaging key stakeholders, including farmers, students, and agricultural advisors, is essential to this process. These stakeholders are not only valuable sources of knowledge but also influential decision-makers in the agricultural sector. Their active involvement and perspectives are vital for successfully integrating smart farming technologies into existing agricultural systems (Kanesh et al., 2022)

This study, conducted as part of the Robs4Crops (R4C) project (Project Website. URL: https://www.robs4crops.eu/), seeks to address these challenges by exploring stakeholder perspectives on the adoption of robotic technologies in agriculture leveraging Scale-Up Demonstrations (SUDs) conducted within the project's context. The research adopts a stakeholder-driven approach to examine both the benefits and barriers associated with these innovations. Feedback from diverse stakeholders, including farmers, agricultural advisors, agribusiness representatives, and students, is critical in understanding the real-world applicability and limitations of these technologies.

## 2. Methodology

### 2.1. Study Context

This study was conducted during the final year (2024) of the R4C project within the framework of SUDs at all R4C pilot sites in France, Greece, Spain, and the Netherlands. These demonstrations were designed to engage and collect feedback from diverse stakeholders, including farmers, advisors, and agribusiness representatives. Additionally, R4C's Farming Controller and Digital Twin (FC & DT) SUDs were held at the premises of the Agricultural University of Athens (AUA) to engage agricultural students, both undergraduate and postgraduate, who represent the future of agriculture.

#### 2.1.1. R4C Pilot's SUDs

The French pilot site focused on developing and showcasing two CEOL robots for autonomous mechanical weeding operations in vineyards. These robots were presented to stakeholders through live field demonstrations. In the Netherlands, the project developed and demonstrated the ROBOTTI platform, designed for autonomous mechanical weeding and seeding operations in arable crops, specifically sugar beets. In Spain and Greece, the focus was on developing autonomous tractors for spraying operations. In Spain, the tractor was utilised for spraying operations in apple orchards, while in Greece, it was used in vineyards. Live demonstrations in these two countries showcased the capabilities of the tractors to stakeholders in real-field conditions relevant to each context.

In all R4C pilot sites, during SUDs participants were exposed to the live demonstrations of the robotic solutions developed in their respective countries. Additionally, they were provided with an overview of the entire project and informed about the robotic solutions developed at other pilot sites. At the end of each demonstration, participants were invited to complete a survey and share their feedback, which formed a critical component of the study. Figure 1 presents photos from the pilot SUDs, capturing the essence of these interactive demonstrations and the engagement process.


*Figure 1. Photos from the R4C pilot SUDs*

### 2.1.2. FC & DT SUDs

At the AUA premises, the FC & DT SUDs conducted for agricultural students provided an overview of the R4C concept and showcased the robotic solutions developed at each pilot site through videos. These demonstrations placed particular emphasis on the R4C Farming Controller, a software tool designed to remotely operate the developed robotic solutions. The Digital Twin was utilised in combination with the R4C Farming Controller to remotely monitor the robots, simulating the field environment and the equipment used during operations. This provided critical information for the execution of missions. For the live demonstration, the R4C Farming Controller software was connected to a small robotic platform (Hasky), executing missions and commands to allow students to witness the software in action. Figure 2 presents photos from the FC & DT SUDs, capturing the essence of these interactive demonstrations and the engagement process.


*Figure 2. Photos from the R4C FC & DT SUDs*

### 2.2. Research Design

The study adopts a mixed-methods approach to comprehensively explore stakeholder perceptions of robotic solutions in agriculture. The design integrates both quantitative and qualitative data collection and analysis to ensure a holistic understanding of the benefits, barriers, and solutions related to the adoption of smart farming technologies.

### 2.3. Data Collection

For the data collection, both surveys (used in R4C pilot's SUDs and FC & DT SUDs) consisted of both quantitative and qualitative questions to comprehensively evaluate participant perceptions and experiences. Quantitative items included Likert-scale questions designed to assess the perceived benefits, barriers, and overall satisfaction with the R4C robotic solutions. Examples of these questions included ratings for the quality of the demonstrations and evaluations of the information provided during the events. The Likert-scale questions were designed following best practices outlined by Vannette and Krosnick (2014), ensuring reliability and standardisation in the responses collected.

Qualitative items included open-ended questions aimed at capturing detailed feedback on participants' perceptions of challenges and solutions for market adoption, as well as suggestions for improving future demonstrations. To complement these, multiple-choice predefined response formats were also employed to structure categorical data effectively. The use of multiple-choice questions was informed by frameworks from Bradburn et al. (2004) and Tourangeau et al. (2000), which highlight the utility of predefined responses in reducing cognitive load and improving data comparability.

#### 2.3.1. Survey for R4C pilots' SUDs in Four Countries

The survey for the R4C pilots' SUDs in France, Greece, Spain, and the Netherlands targeted a broad and diverse group of stakeholders, including farmers, advisors, and representatives from agribusinesses. Participants included 44 individuals from Spain, and approximately 20 from France, Greece and the Netherlands collecting a total of 104 responses. A Google Form was utilised to collect feedback during the demonstrations.

The survey structure was designed to gather insights across several categories, including participant background and affiliation, evaluation of demonstration activities, factors influencing attendance, familiarity with robotic farming, quality of disseminated information, and changes in perceptions. It also explored challenges and potential solutions in the market adoption of robotic technologies, along with recommendations for improving the relevance and quality of future events. The following Table 1 presents the questionnaire used for the feedback collection survey.

*Table 1 Questionnaire for R4C pilots' SUDs*

| Category | Questions |
|---|---|
| Participant Background and Affiliation | **1.** What best describes your professional role or affiliation? (Farmer; Technology provider; Regulatory body; Research/Academia; Other) |
| Evaluation of Demonstration Activities | **2.** Please indicate which of the following demonstration activities you attended: (France: Vineyards & Vegetables mechanical weeding; Greece: Table grapes spraying; Spain: Apple orchards spraying; Netherlands: Weeding in potato cropping systems)<br><br>**3.** How would you rate the demonstration activities for this pilot on a scale of 1 (poor) to 5 (excellent)? |
| Factors Influencing Attendance | **4.** What factors influenced your decision to attend the demonstration activities for this pilot? (Interest in robotic farming technologies; Keenness to learn about the R4C project; Potential impact on my professional practice or business; Recommendation from a colleague or industry professional) |
| Familiarity with Robotic Farming | **5.** Before attending the demonstration activities, how familiar were you with the concept of robotic farming? Please rate your familiarity on a scale of 1 (not at all familiar) to 5 (very familiar).<br><br>**6.** Do you feel that the demonstration activities enhanced your understanding of robotic farming? (Yes/No) |
| Quality of Disseminated Information | **7.** How would you rate the quality of the information and knowledge disseminated during the demonstration activities? Rate it on a scale of 1 (poor) to 5 (excellent).<br><br>**8.** Did the demonstration activities alter your perception of the potential benefits of robotic farming? (Yes/No)<br><br>**9.** If yes, could you please elaborate on the specific benefits that you found most compelling? |
| Challenges and Solutions in Market Adoption | **10.** What challenges do you predict in the market adoption of robotic farming technologies? What possible solutions or strategies could help address these challenges? |
| Suggestions for Improvement | **11.** What suggestions do you have for improving future demonstration events or activities related to robotic farming technologies? |

The demonstrations were conducted in real-world agricultural settings, incorporating hands-on interaction and live scenarios to showcase the practical application of robotic solutions. Feedback was collected in five different languages (English, French, Greek, Spanish, and Dutch) to ensure accessibility and inclusivity for participants from all four countries.

#### 2.3.2. Survey for FC & DT SUDs to students

The survey for FC & DT SUDs at the AUA targeted undergraduate and postgraduate students engaging a total of 54 participants. A Google Form was utilised to collect feedback during the demonstrations.

The survey was structured to gather comprehensive feedback across five categories: a) familiarity and understanding of technologies, b) demonstration impact and perception, c) interactive experience and further interest, d) enthusiasm and user-friendliness, and e) benefits, challenges, and enhancements. It aimed to evaluate the effectiveness of the demonstrations, participants' engagement, and their perspectives on the future applicability of these technologies. Table 2 presents the questionnaire used for the feedback collection survey.

*Table 2 Questionnaire for R4C FC & DT SUDs*

| Category | Questions |
|---|---|
| Familiarity and Understanding of Technologies | **1.** Before this demonstration, how familiar were you with digital farming tools like the Farming Controller combined with Digital Twins? (1 - Not familiar at all; 5 - Very familiar) |
| Demonstration Impact and Perception | **2.** Did the demonstration improve your understanding of how the Farming Controller combined with Digital Twins work? (Significantly Improved; Improved; No Change; Became More Confused)<br><br>**3.** Do you see the Farming Controller combined with Digital Twins as playing a crucial role in the future of agriculture? (1 - Definitely No; 5 - Definitely Yes) |
| Interactive Experience and Further Interest | **4.** Would an interactive experience with this technology make the demonstration more appealing or insightful to you? (1 - Definitely No; 5 - Definitely Yes)<br><br>**5.** Would you be interested in a more in-depth training material or a course focusing on these technologies and their practical applications? (Very interested; Interested; Neutral; Not Really Interested; Not at all Interested) |
| Enthusiasm and User-Friendliness | **6.** Given what you've observed, how enthusiastic are you about the possibility of engaging with such technologies in your future agricultural career? (1 - Not excited at all; 5 - Very excited)<br><br>**7.** How would you rate the user-friendliness of the Farming Controller and Digital Twins technologies based on the demonstration you witnessed? (1 - Not user-friendly at all; 5 - Very user-friendly) |
| Benefits, Challenges, and Enhancements | **8.** In your opinion, what are the most promising benefits of integrating the Farming Controller with Digital Twins in modern farming?<br><br>**9.** What do you perceive as potential challenges or barriers for agricultural professionals when adopting these combined technologies? What possible solutions or strategies could help address these challenges?<br><br>**10.** How could we enhance such demonstrations to be more engaging and beneficial for students like you? |

The demonstrations for the FC & DT SUDs were conducted in an educational setting, incorporating both live interaction and multimedia presentations to showcase the practical application of the R4C technologies. A live demonstration with the Hasky robotic platform allowed students to interact with the FC in action, while videos presented the complete range of robotic solutions developed in the R4C pilots. Feedback was collected through a survey available in five languages (English, Greek, French, Spanish, and Dutch) to ensure accessibility and inclusivity. All responses were translated into English to facilitate a unified analysis.

### 2.4. Ethical Considerations

To ensure ethical integrity, all participants were fully informed about the study's purpose, how their data would be used, and their right to withdraw at any point without any consequences. All survey responses were anonymised, guaranteeing confidentiality throughout the research process. Inclusivity was prioritised in the SUDs, with surveys translated into four languages, Greek, Dutch, Spanish, and French, to align with the diverse stakeholder groups involved in the R4C pilots across the accommodating countries. For the demonstrations of the FC and DT solutions conducted with students at the AUA, surveys were provided in Greek and English, reflecting the linguistic needs of the participants in that specific context.

### 2.5. Data Analysis

The data collected from the R4C pilots' SUDs and the FC & DT demonstrations were analysed using quantitative and qualitative methods. Quantitative analysis focused on summarising responses to Likert-scale and multiple-choice questions. Descriptive statistics were used to identify overall trends, such as participant perceptions of technology usability, accessibility, and benefits. Comparative analyses were conducted to explore differences in responses based on demographic factors, including familiarity with digital tools and professional background. These methods ensured a statistical interpretation of participant feedback, providing a clear understanding of general patterns and variations in stakeholder perspectives.

For qualitative data, thematic analysis was applied to responses from open-ended survey questions. This involved coding and categorising text data to identify recurring themes and patterns. Emergent themes were grouped into key categories that reflected participant insights into the usability of the technologies, their educational value, and suggestions for improvement. The thematic analysis aimed to provide a comprehensive understanding of participants' experiences and to capture nuanced perspectives that quantitative methods could not fully address.

Both quantitative and qualitative analyses were conducted in parallel to ensure a comprehensive evaluation of the collected data. The integration of statistical summaries with thematic insights provided a holistic understanding of participant feedback, allowing for the identification of actionable recommendations and strategies to enhance the adoption of robotic and digital farming technologies. This mixed-methods approach ensured that the analysis captured both measurable trends and the underlying context of participant experiences.

## 3. Results

### 3.1. Results from feedback analysis during SUDs in R4C four countries

**Participant Background and Affiliation**

Survey data across the four countries revealed a diverse range of stakeholder backgrounds and affiliations, highlighting the widespread interest in robotic farming technologies across various sectors. Participants were primarily affiliated with research institutions and agricultural organizations, with smaller proportions from farm management, private industry, and other roles. In France, 80% of respondents were farmers, while the remaining 20% represented a mix of roles, including technology suppliers, regulatory bodies, and research/academia. In the Netherlands, a similar distribution was observed, with farmers constituting the largest percentage, representing 90% of respondents. In Spain farmers accounted for 72.7% of respondents, offering a robust practical perspective from individuals actively involved in agricultural activities. Additionally, 15.9% of participants were from the research and academic community, contributing valuable insights grounded in scientific expertise. While there was no representation from technology providers, 9.1% of respondents identified roles not explicitly mentioned, and a smaller percentage represented regulatory bodies, ensuring a diverse range of viewpoints for the sector. Lastly, in Greece, farmers constitute 65% of the participants, highlighting a significant presence of individuals directly involved in agricultural practices. A notable 25% of the participants implies a variety of roles not explicitly mentioned in the provided options, while the remaining categories such as research/academia professionals and Technology providers accounted for a very small percentage (Figure 3).

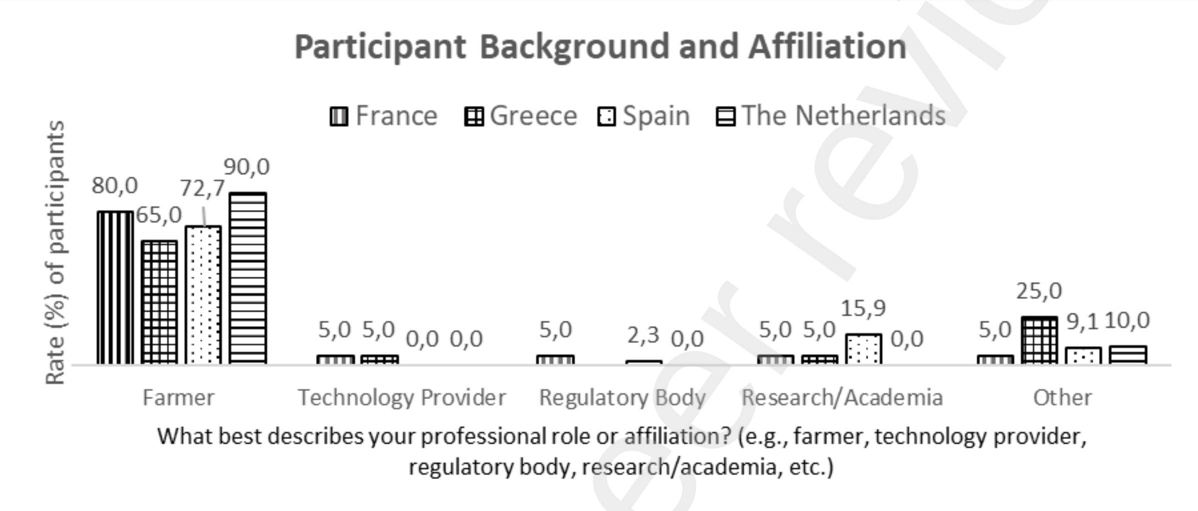



*Figure 3. Distribution of Participant Background and Affiliation - Bar Chart*

**Evaluation of Demonstration Activities**

The evaluation of demonstration activities revealed that the majority of participants in each country were satisfied with the demonstrations. In France, 85% rated the activities either 4/5 or 5/5, with only 15% providing a moderate 3/5 score. In the Netherlands, 80% gave a high rating (4/5 or 5/5), and no respondents rated the demonstrations poorly. Spain had 88.6% positive feedback (47.7% 4/5, 40.9% 5/5), with just 11.4% rating it average. Greece also showed strong approval, with 90% rating it positively (45% 5/5, 45% 4/5). (Figure 4)

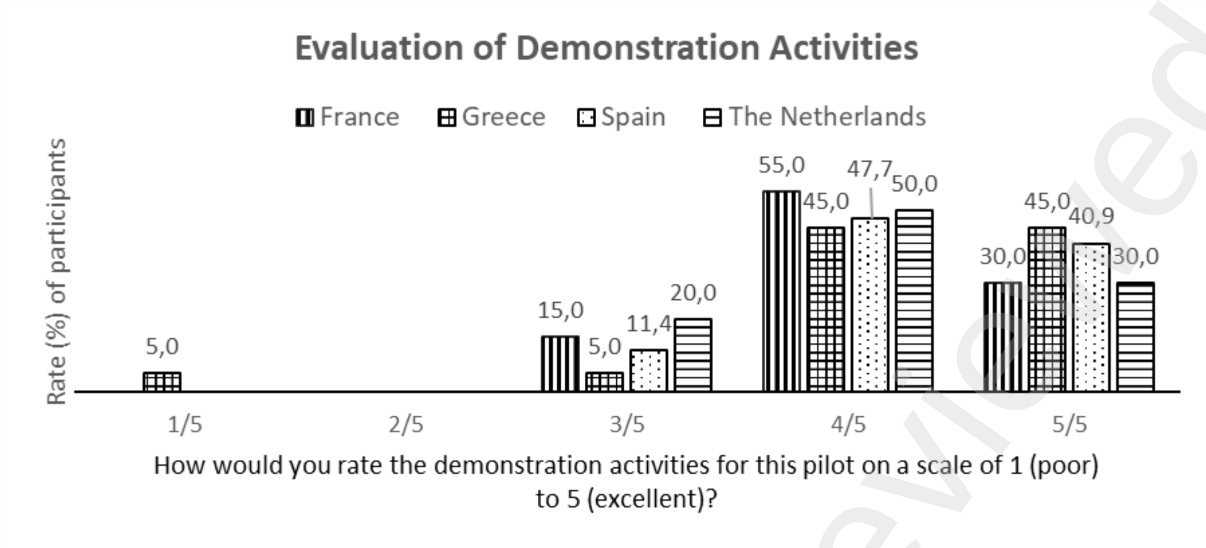



*Figure 4. Feedback for the evaluation of demonstration - Bar Chart*

**Factors Influencing Attendance**

The survey, designed to capture the complex motivations behind participants' engagement, included multiple component options. The reasons behind participants' attendance at the demonstrations were relatively consistent across countries. In France, a total of 20 participants provided 39 responses, revealing that 80% attended out of interest in robotic agricultural technology, while 60% were motivated by its potential impact on their professional practices, and 45% were influenced by referrals from coworkers or industry experts. In the Netherlands, a total of 22 responses were gathered from 20 participants, also providing valuable insights into the main factors influencing participation in the demonstration events. Notably, 60% cited interest in robotic technology as the main motivational factor, followed by 40% indicating potential professional impact. Interestingly, none of the respondents expressed specific interest in the R4C project itself. In Spain, a total of 78 responses were collected from 44 participants, with 86.4% motivated by interest in robotic farming, and 47.7% wanting to learn about the R4C project. In Greece, a total of 29 responses were collected from 20 participants, with 40% motivated by an interest in robotic farming technologies, 40% by a desire to learn about the R4C project, and 35% by the potential impact on their professional practices or business. The remaining 30% mentioned recommendations from colleagues or industry professors as their key motivational factor. The results regarding the key factors influencing participants' attendance are presented in figure 5.

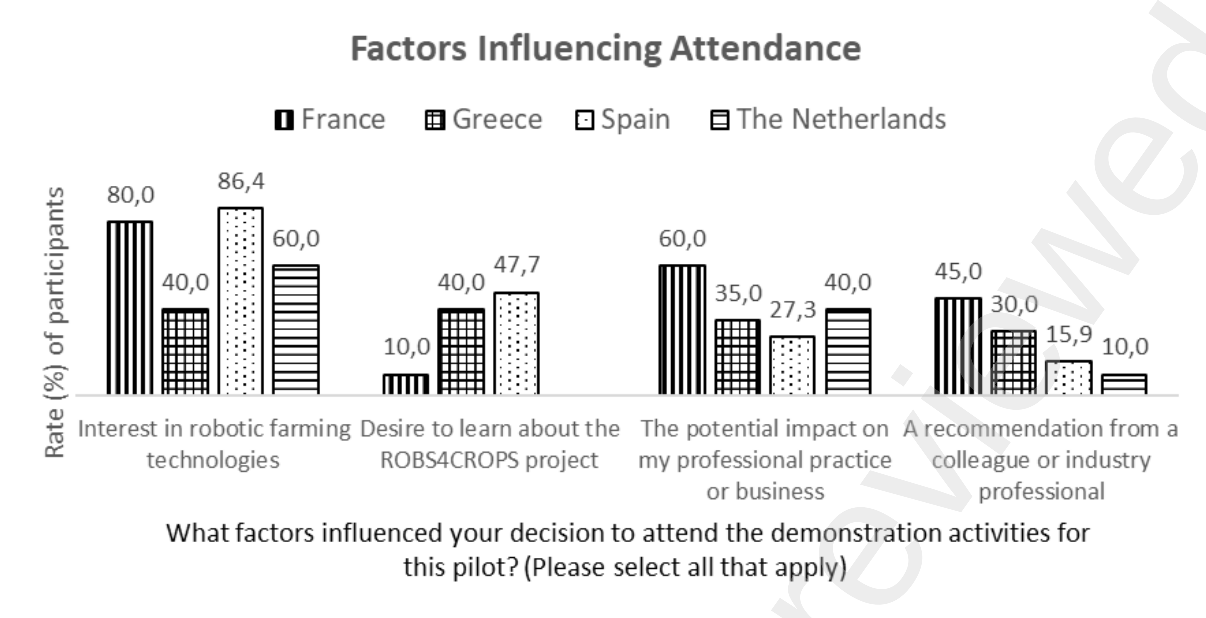



*Figure 5. Feedback for the factors affecting attendance - Bar Chart*

**Familiarity and Understanding of Robotic Farming**

The majority of participants varied in terms of levels of familiarity with robotic farming. In France, a 20% reported advanced familiarity (5/5), while 10% indicated limited prior knowledge (2/5). The majority, 70%, demonstrated a moderate level of familiarity, with ratings of 3/5 and 4/5. Furthermore, 90% of participants responded positively to a follow-up question on whether the demonstrations had increased their understanding, highlighting the effectiveness of the activities in achieving their learning objectives. The remaining 10% expressed unfavourable opinions, indicating a need for additional information and support to enhance their comprehension of robotic farming. The survey results from the Netherlands on familiarity with robotic farming prior to the demonstration revealed that 50% of respondents rated their familiarity as 4/5 or 5/5 with 40% and 10% respectively, indicating higher levels of knowledge. Meanwhile, 30% reported moderate familiarity at 3/5, and 20% rated their knowledge as 2/5. In response to a follow-up question on whether the demonstrations had enhanced participants' comprehension, 80% of respondents answered positively, while 20% negatively. For the majority of participants, this suggests that the demonstration was successful in meeting its educational goals. However, the 20% who felt their understanding had not improved highlighted areas for improvement. In Spain, the survey revealed a small proportion of participants at both extremes: 11.4% rated their familiarity as 1/5, and 6.8% rated it as 5/5. The remaining 81.8% of respondents fell within the middle ratings of 2/5, 3/5, and 4/5, indicating a broad range of exposure to robotic farming. A follow-up question regarding whether the demonstrations had improved participants' understanding received a unanimous "Yes" from all respondents, indicating 100% positive feedback. In contrast, participants' responses in Greece showed a more limited prior knowledge of robotic farming technologies. Of the respondents 20% stated limited prior knowledge (rating 1/5), while only 5% expressed advanced familiarity (rating 5/5). The middle ground (ratings 2/5, 3/5, and 4/5) accounts for a significant 75%, illustrating a spectrum of moderate familiarity. In addition, a subsequent question on whether the demonstrations had improved understanding of the participants received positive feedback of 100% 'yes'. The results regarding participants' prior familiarity with robotic farming are presented in Figure 6.

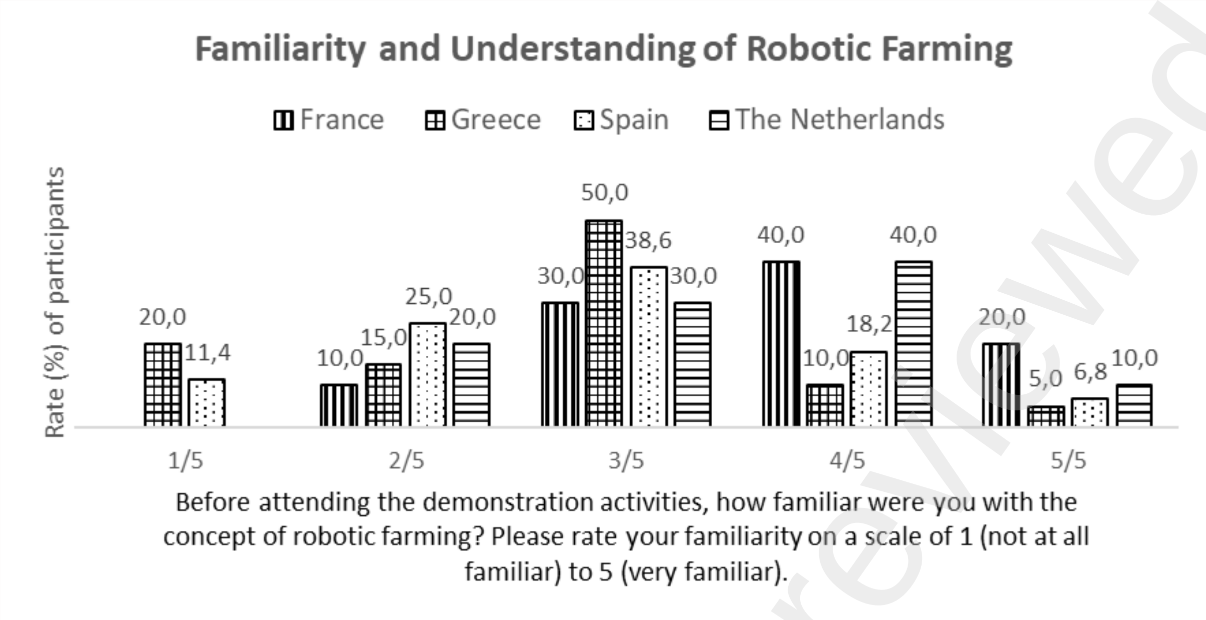



*Figure 6. Feedback for Familiarity and Understanding of Robotic Farming - Bar Chart*

**Quality of Information and Perception Change**

Participants' perceptions of robotic farming were notably influenced by the quality of information presented during the demonstration activities. When asked about the quality of the knowledge shared, responses were largely positive, highlighting the effectiveness of the information in enhancing participants' understanding of the technology. In France, the survey results indicated a strong positive response, with 30% of participants giving the maximum rating of 5/5 and 50% rating it 4/5. In the Netherlands, participants' evaluations were similarly positive, with most ratings being average or higher. Specifically, 20% rated the quality as 3/5, 50% rated it 4/5, and 30% gave it an excellent score of 5/5. In Spain, 88.6% of respondents rated the quality as either very good (4/5) or excellent (5/5), with only 2.3% rating it as poor (2/5), indicating a strong overall satisfaction with the information provided. In Greece, feedback was also highly satisfactory, with 50% giving the highest rating of 5/5 and an additional 45% rating it 4/5. (Figure 7)

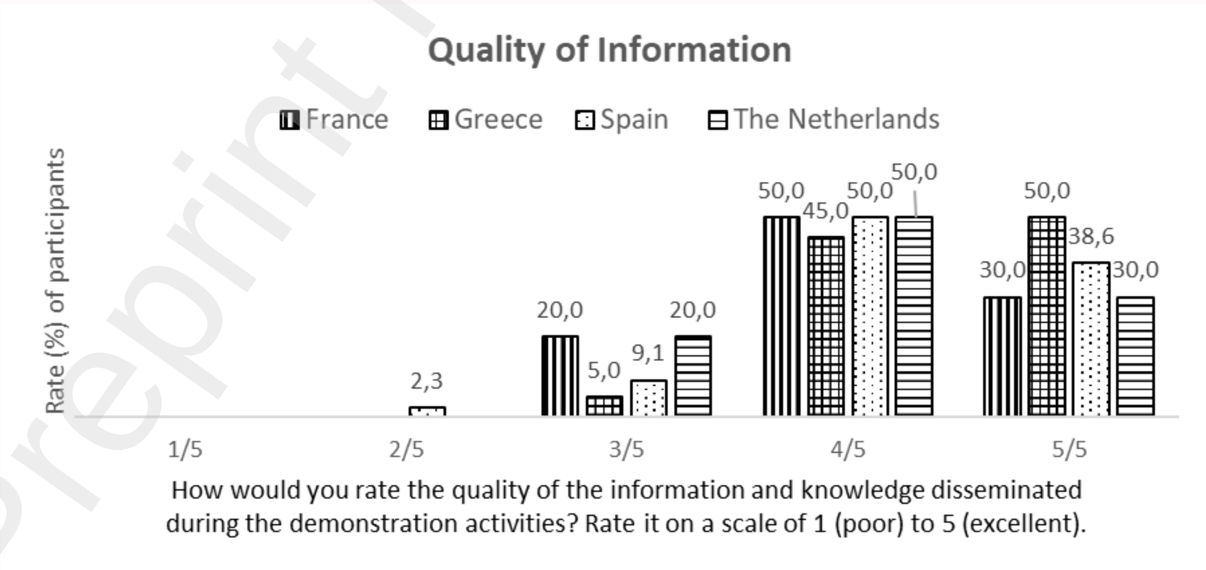



*Figure 7. Quality of Information disseminated to all countries -Bar Chart*

In terms of whether the demonstration activities changed participants' perceptions of the potential benefits of robotic farming, responses varied across countries. In France, 80% of respondents stated that the demonstrations had altered their opinion on the potential benefits of robotic farming, indicating a strong positive impact. In the Netherlands, however, the responses were more varied, with 40% of participants expressing doubts about the benefits of the technology despite the high-quality information provided. In Spain, the demonstrations had a significant influence, with 88.6% affirming that their perceptions had changed positively, though a small group of participants remained unconvinced about the benefits. Meanwhile, in Greece, 100% of respondents reported that their perceptions of the potential benefits of robotic farming had been positively influenced by the demonstration activities, underscoring the success of the event in altering perceptions. (Figure 8)

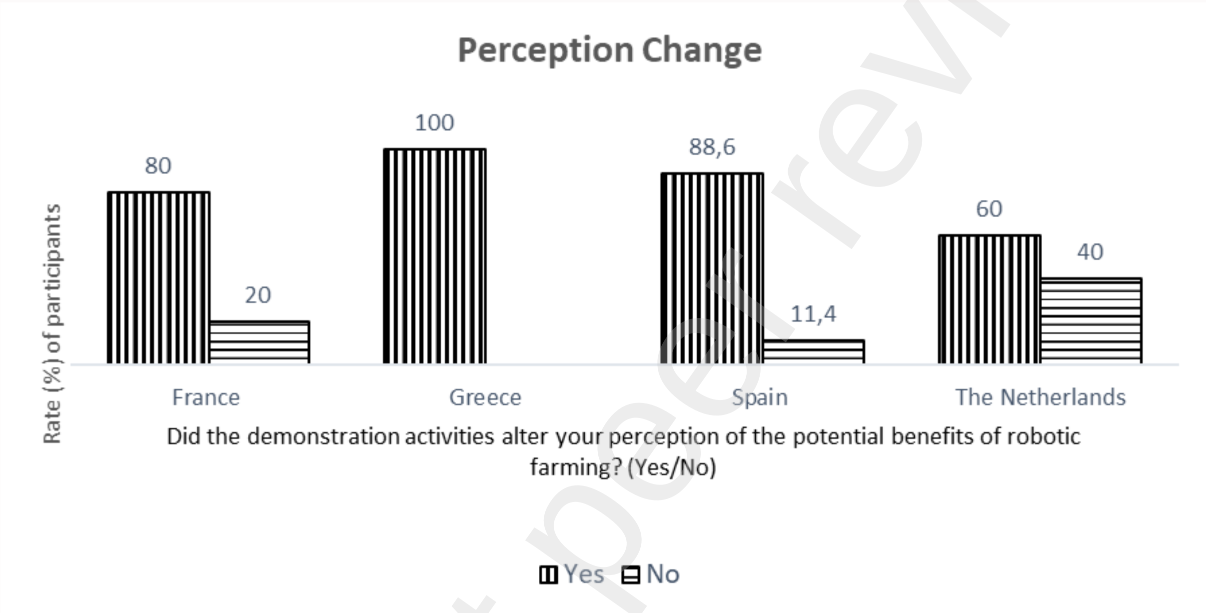



*Figure 8. Distribution of Perception Change from all countries -Bar Chart*

Following the question on whether the demonstration activities altered participants' perceptions of the potential benefits of robotic farming, respondents were asked to elaborate on the specific benefits they found most compelling. The insights provided reflect the varying levels of understanding and enthusiasm for robotic farming across the different countries. The following sections highlight the key benefits identified by participants across the different countries.

**France**

The thematic analysis of 20 responses from farmers and advisors in France, following the R4C demonstration activities, identified four key themes regarding the most compelling benefits of robotic farming technologies (Figure 9). The most frequently mentioned benefit was **Labour Reduction** (9 mentions), with respondents repeatedly highlighting the capacity of robotic farming to reduce labour demands significantly. Farmers noted the potential for automation to address labour shortages and ease physical workloads, making it a particularly valuable feature in vineyards and vegetable farming. **Automation** (5 mentions) emerged as another significant theme, emphasising the role of autonomous technologies in enhancing operational efficiency. Participants appreciated features like "automatic driving" and "reliable guidance," which allow for precision and consistency in farming tasks with minimal human intervention. **Productivity and Efficiency Gains** (6 mentions) were also perceived as a key benefit. Responses indicated that robotic technologies could increase productivity and streamline farming processes, with participants citing improvements such as "better farm management" and "increased efficiency". Lastly, **Environmental Benefits** (2 mentions) were identified as an additional advantage. While less frequently mentioned, respondents recognised the potential for robotic systems to support environmentally friendly farming practices, particularly through precision techniques that reduce inputs and minimise environmental impact.

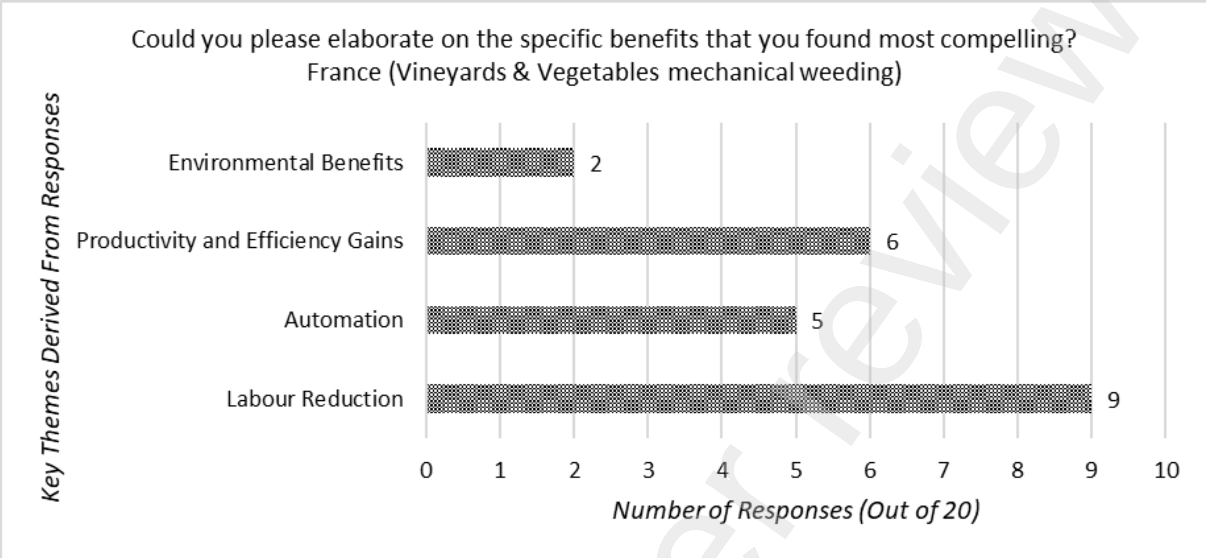



*Figure 9. Feedback on perceived benefits of FC & DT integration to modern farming- French Pilot*

**The Netherlands**

The thematic analysis of 20 responses from farmers and advisors in the Netherlands, following the R4C demonstration activities, identified four key themes regarding the most compelling benefits of robotic farming technologies (Figure 10). The most frequently mentioned theme was **Automation and Autonomy** (8 mentions), with participants highlighting the ability of robotic systems to operate independently and consistently. Responses such as "automacy with those machines" and "autonomy of the hoe and the algorithm" underscored the appreciation for self-operating systems that minimise the need for human supervision while ensuring reliable performance in weeding tasks. **Labour Reduction** (4 mentions) was also a prominent theme, reflecting the value placed on reducing manual labour requirements. Participants frequently noted the potential for robotic systems to alleviate labour shortages and reduce physical demands on farm workers. **Precision and Performance** (5 mentions) emerged as another key theme, with respondents emphasising the importance of accuracy in weeding operations. Phrases such as "precise hoeing" and "camera technology" highlighted the role of robotic systems in improving precision, reducing crop damage, and enhancing overall operational effectiveness. Lastly, **Machine and Tank Capacity** (3 mentions) was noted as an important feature, with responses such as "machine capacity" and "tank capacity" reflecting the value of systems that can handle larger workloads and operate for extended periods without frequent interruptions.

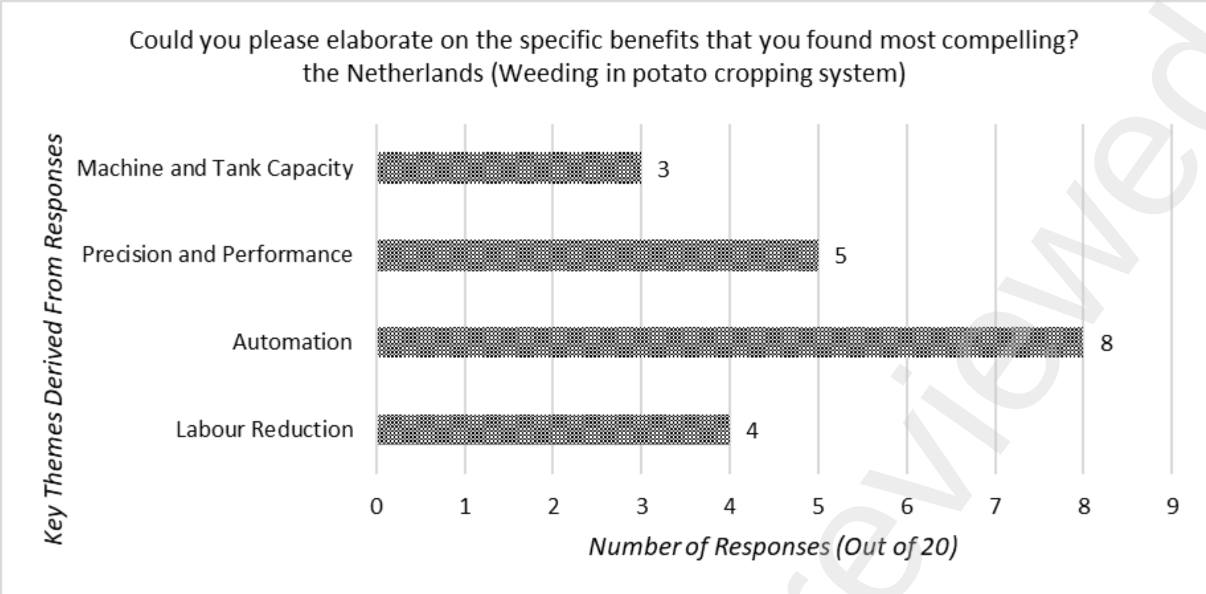



*Figure 10. Feedback on perceived benefits of FC & DT integration to modern farming- Dutch Pilot*

**Spain**

The thematic analysis of 44 responses from farmers and advisors in Spain, following the R4C demonstration activities, identified five key themes regarding the most compelling benefits of robotic farming technologies (Figure 11). The most frequently mentioned theme was **Cost Efficiency** (26 mentions). Participants highlighted how robotic technologies significantly reduce operational costs by lowering labour requirements, increasing resource efficiency, and enabling cost-effective spraying applications. **Labour Reduction** (15 mentions) emerged as another critical theme. Many participants noted that robotic systems alleviate the burden of manual labour, making tasks such as spraying more manageable while addressing labour shortages. **Improved Production and Efficiency** (20 mentions) was also prominent, with participants appreciating how these technologies improve productivity through precision spraying, efficient field management, and streamlined workflows. Statements such as "improved production" and "efficient spraying applications" demonstrated the perceived operational benefits. **Automation and User-Friendliness** (10 mentions) highlighted how automation and ease of use make the technology accessible and practical for farmers. Participants valued features like "automated processes," "easy to use," and advanced capabilities such as "LIDAR cameras," which enhance both usability and efficiency. Lastly, **Less Chemical Use** (8 mentions) reflected the environmental benefits of precision spraying. Respondents emphasised how robotic systems reduce chemical inputs, contributing to environmentally friendly practices and promoting safer working conditions for farmers.

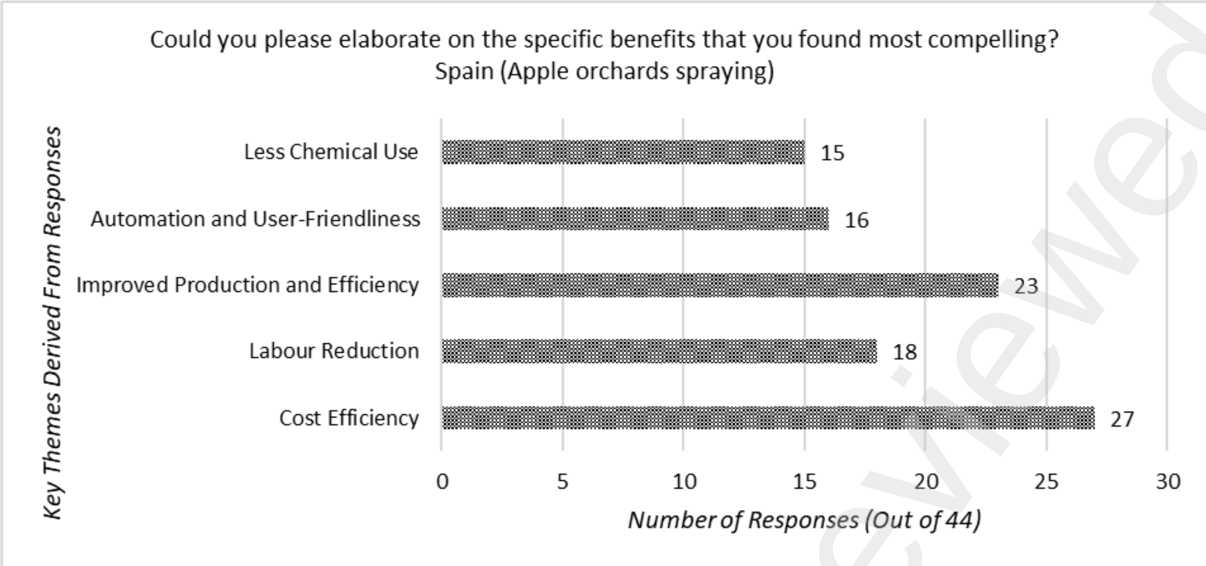



*Figure 11. Feedback on perceived benefits of FC & DT integration to modern farming- Spanish Pilot*

**Greece**

The thematic analysis of 20 responses from farmers and advisors in Greece, following the R4C demonstration activities, identified four key themes regarding the most compelling benefits of robotic farming technologies (Figure 12). The most frequently mentioned theme was **Cost Efficiency** (8 mentions). Participants highlighted how robotic farming technologies significantly reduce production costs, making cultivation more economical. **Labour Reduction** (5 mentions) was also a prominent theme, with participants noting the ability of robotic systems to save labour costs and simplify cultivation tasks. **Precision and Efficiency** (4 mentions) emerged as another key theme, with participants appreciating the accuracy and improved effectiveness of robotic systems. Responses such as "great ease and precision of operations" and "improved effectiveness" underscored the value of precise spraying techniques that optimise resources and enhance productivity. Finally, **Less Chemical Use** (3 mentions) reflected the benefits of reduced chemical input through robotic spraying technologies. Participants highlighted advantages such as "spraying liquid economy" and "reduction of exposure to pesticides," which promote sustainability and safer farming practices.

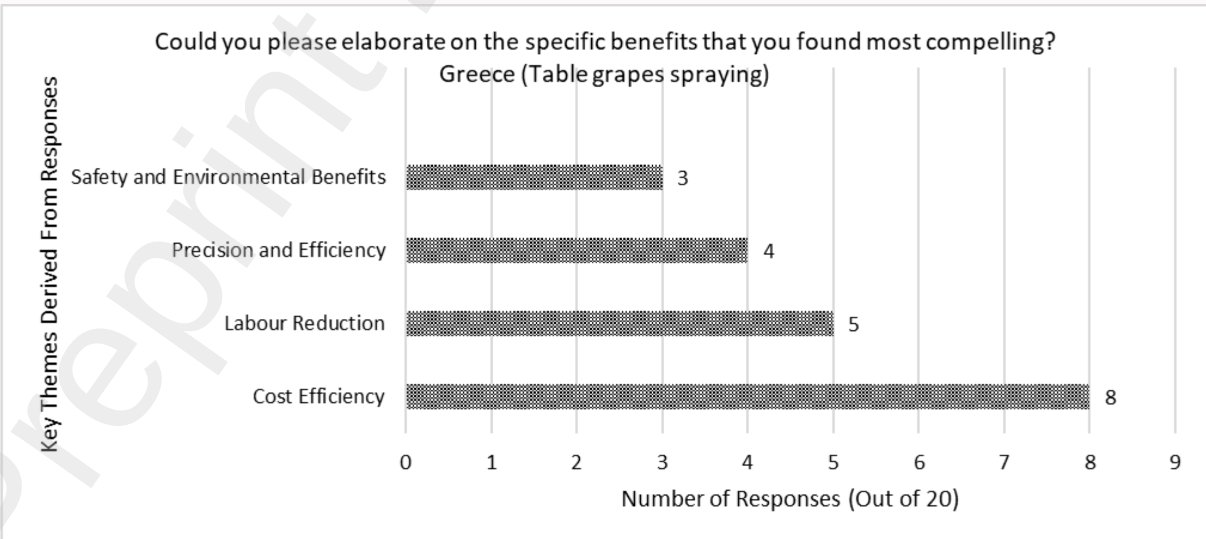



*Figure 12. Feedback on perceived benefits of FC & DT integration to modern farming- Greek Pilot*

### Challenges and Solutions in Market Adoption

#### France

The thematic analysis of 20 responses from farmers and advisors in France identified four key challenges to the market adoption of robotic farming technologies (Figure 13). The most frequently mentioned challenge was **Lack of Knowledge and Awareness** (7 mentions). This suggests the need for educational initiatives to raise awareness and provide technical training. **High Initial Cost** (6 mentions) emerged as another significant challenge, with participants repeatedly emphasising the financial burden of adopting robotic systems. **Legislative and Regulatory Barriers** (4 mentions) were also cited as a concern. Participants mentioned issues such as "legislation on remote supervision" and "binding legislation on autonomous driving," indicating that restrictive regulations may hinder the deployment of robotic farming systems in the agricultural sector. Finally, **Lack of Trust in Technology** (3 mentions) was identified as a barrier, with some farmers expressing scepticism about the reliability and effectiveness of robotic systems.

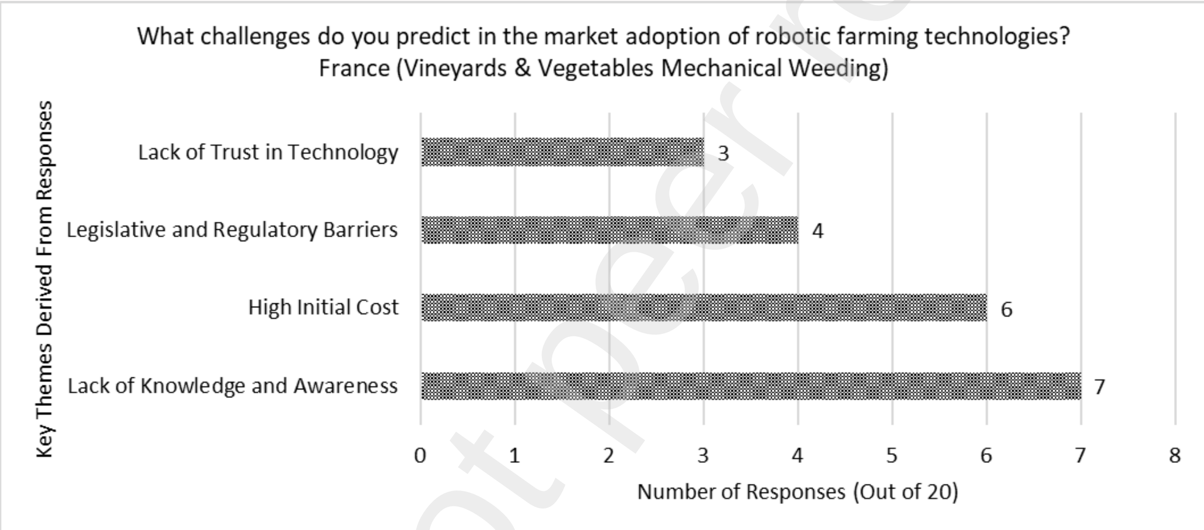



*Figure 13. Challenges in Market Adoption identified by French Pilot*

The identified solutions to address the challenges of adopting robotic farming technologies include **supportive legislation on autonomous driving** (4 mentions) and **access to communal paths** (2 mentions) (Figure 14). These solutions emphasise the need for **regulatory adjustments** to streamline the implementation of autonomous systems and **infrastructural improvements**, such as providing access to communal paths, to enhance the logistical feasibility and efficiency of these technologies.

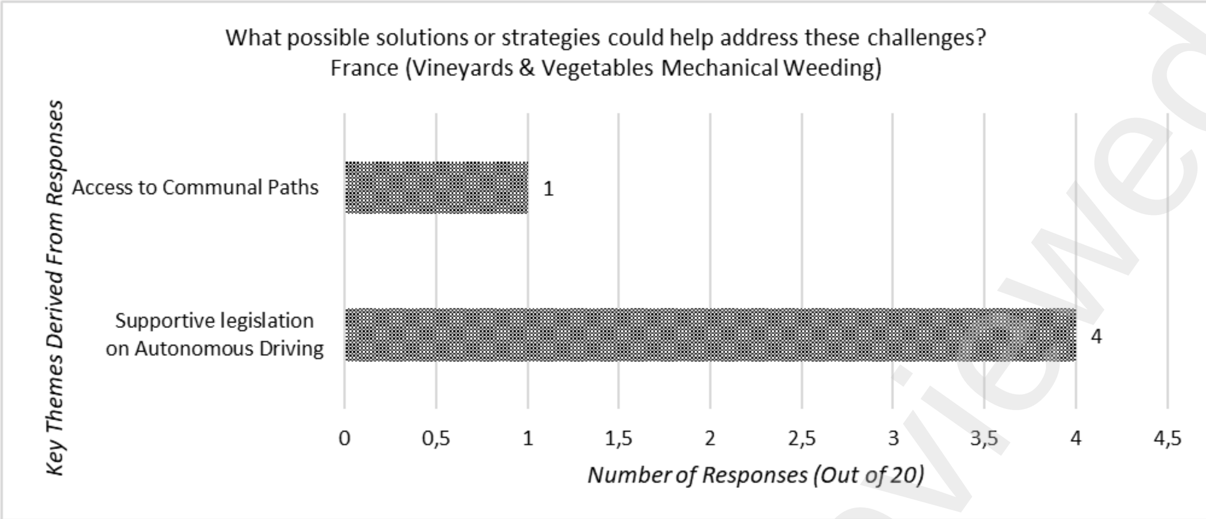



*Figure 14. Solutions in Market Adoption identified by French Pilot*

## The Netherlands

The thematic analysis of responses from 20 participants in the Netherlands, following the R4C demonstration activities, revealed three primary challenges to the market adoption of robotic farming technologies (Figure 15). The most frequently mentioned challenge was **Lack of Knowledge and Guidance** (10 mentions). Participants consistently highlighted a lack of understanding and technical knowledge about robotic farming technologies, emphasising "not enough knowledge" and "the need for instruction and guidance." This indicates a need for targeted education and training initiatives to improve familiarity and ease of use among farmers. **Replacement of Manual Labour** (4 mentions) emerged as another significant concern. Responses such as "replacement of manual work" reflected apprehension about the potential displacement of traditional farming jobs and the social implications of integrating robotic technologies into existing workflows. **Data Privacy Concerns** (2 mentions) were also identified, with participants expressing hesitation about how data collected by robotic systems would be managed, stored, and used. These concerns highlight the importance of transparency and robust data protection measures in fostering trust and adoption.

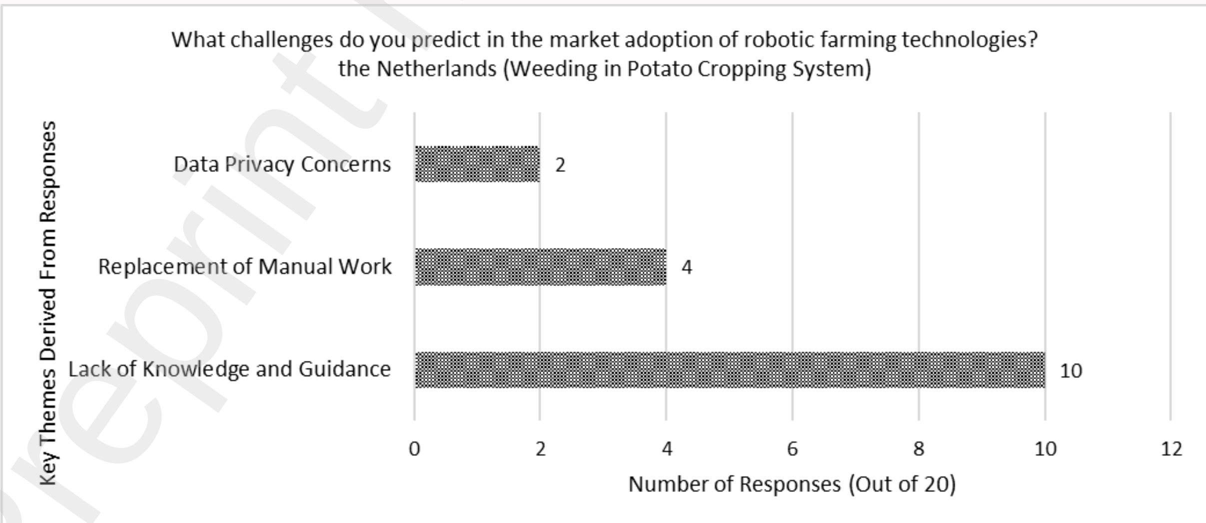



*Figure 15. Challenges in Market Adoption identified by Dutch Pilot*

In terms of solutions, while most participants did not propose specific strategies, a small subset recommended **Robust Data Privacy Regulations** (2 mentions) and **Building Trust** (2 mentions) (Figure 16). These suggestions emphasised the need for strong data protection policies and confidence-building efforts, such as transparent communication and demonstrations of reliability, to address hesitations around data privacy and technology adoption.

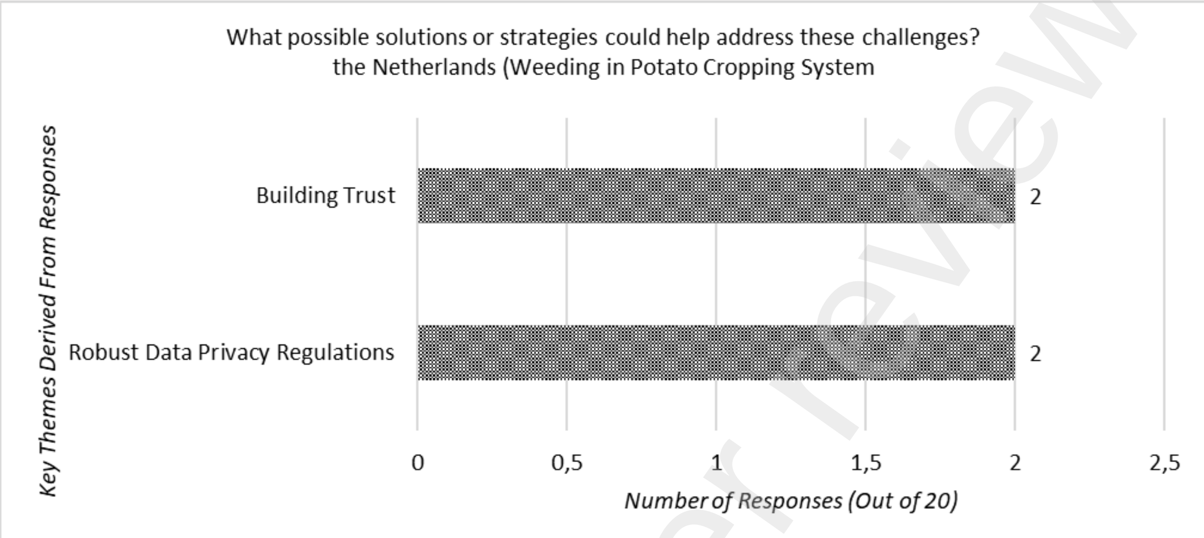



*Figure 16. Solutions in Market Adoption identified by Dutch Pilot*

**Spain**

The thematic analysis of responses from 44 participants in Spain identified several challenges regarding the market adoption of robotic farming technologies (Figure 17). The most frequently cited challenge was **Lack of Education and Expertise** (22 mentions). Farmers and advisors highlighted "lack of education," "insufficient knowledge," and "lack of expertise" as significant barriers. This reflects a need for increased awareness and technical training to improve understanding and adoption of robotic farming systems. **Resistance from Older Generations** (10 mentions) was another prominent challenge. Participants noted scepticism or reluctance among older farmers, with phrases such as "resistance from older generations" and "lack of acceptance" reflecting hesitation to move away from traditional farming methods. **High Implementation Costs** (10 mentions) also emerged as a critical barrier. Comments like "high-cost implementation" and "financial barriers" highlighted concerns about affordability, particularly for smaller-scale farmers. **Complexity and Ease of Use** (6 mentions) was another notable theme, with participants mentioning that the technology could be "difficult to use" or "complicated to operate," especially for less tech-savvy farmers. Finally, **Transport and Accessibility Issues** (2 mentions) reflected logistical concerns, such as "transport of the robots," which could impede the seamless integration of robotic systems into farming practices.

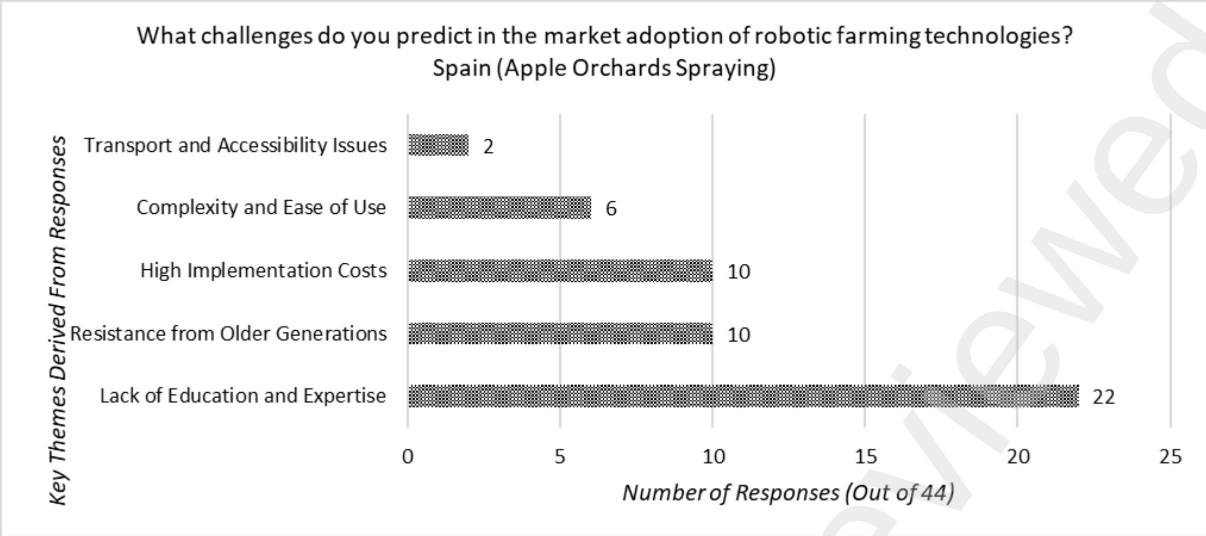



*Figure 17. Challenges in Market Adoption identified by Spanish Pilot*

Participants proposed a variety of solutions to address these challenges (Figure 18). The most frequently mentioned solution was **Educational Opportunities** (21 mentions), with participants emphasising the need for "seminars," "educational presentations," and "free training" to improve farmers' knowledge and skills. **Demonstrating Benefits and Real-Time Applications** (7 mentions) was also highlighted, with participants suggesting that showcasing the "economic benefits" and "practical applications" of robotic farming systems could increase acceptance, particularly among older generations. **Financial Support Mechanisms** (6 mentions), such as "funding" and "subsidies," were proposed to mitigate the high implementation costs of these technologies. Lastly, **Simplified Systems and User-Friendly Tools** (5 mentions) were suggested to address complexity concerns, with recommendations for "user-friendly manuals," "applications," and "updates" to enhance accessibility.

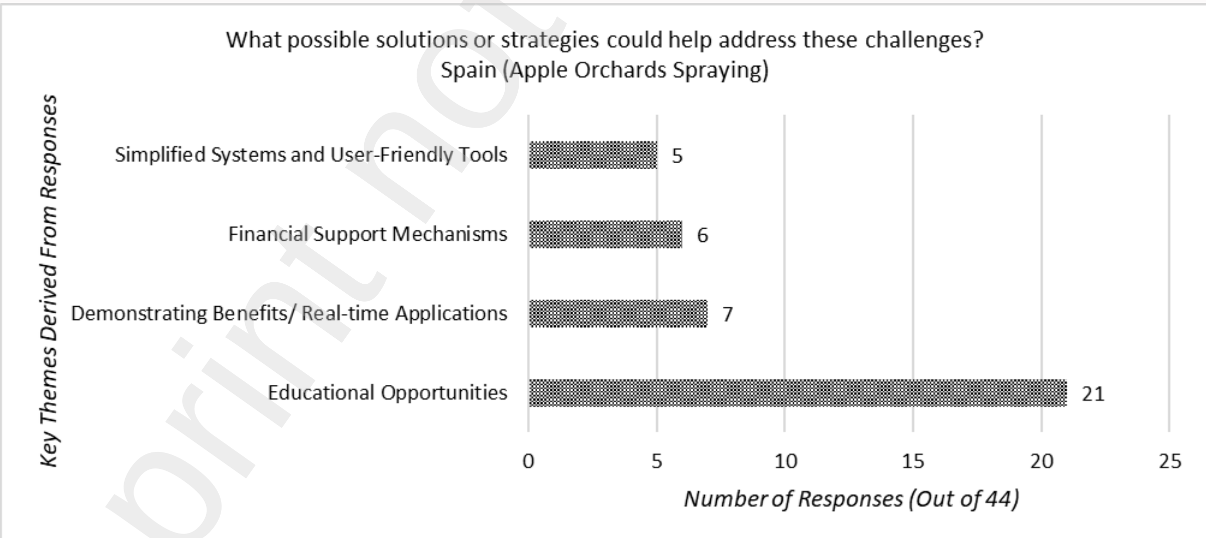



*Figure 18. Solutions in Market Adoption identified by Spanish Pilot*

**Greece**

The thematic analysis of 20 responses from farmers and advisors in Greece identified several key challenges for the market adoption of robotic farming technologies (Figure 19). The most frequently cited challenge was **Lack of Knowledge and Expertise** (8 mentions), with participants emphasising that many farmers lack the technical skills required to operate, maintain, and troubleshoot robotic systems effectively. **High Initial Costs and Lack of Capital** (7 mentions) also emerged as a significant barrier, with participants highlighting affordability concerns, particularly for small-scale farmers. **Resistance to Change** (3 mentions) was another notable challenge, particularly among older farmers who were sceptical about the effectiveness and reliability of new technologies. Additional barriers included **Operational Complexity** (2 mentions), with some farmers finding robotic systems difficult to use, and **Limited Accessibility** (2 mentions), as the technology was perceived to be available only to a few farmers due to financial or logistical constraints.

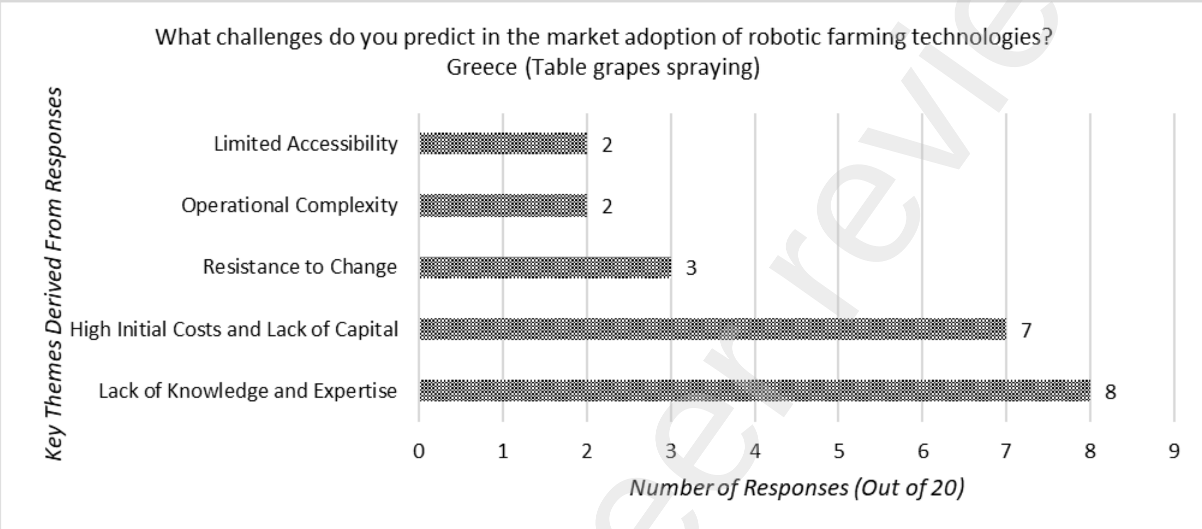



*Figure 19. Challenges in Market Adoption identified by Greek Participants*

Participants proposed several solutions to address these challenges (Figure 20). **Educational Opportunities and Training Programs** (9 mentions) were the most frequently recommended, with respondents advocating for workshops, online resources, and informative seminars to improve farmers' knowledge and technical expertise. **Financial Support Mechanisms** (6 mentions), such as investment programs, subsidised access, and demonstrating long-term cost savings, were suggested to address the high initial costs. To overcome resistance to change, participants recommended **Highlighting Benefits and Building Trust** (3 mentions) by showcasing the long-term economic and operational advantages of robotic systems. Additionally, fostering **Cooperative and Inclusive Farming Models** (2 mentions), such as collaboration between older and younger farmers, was proposed to encourage technology sharing and adoption. Lastly, **Simplifying Systems** (2 mentions), through user-friendly interfaces and tools, was highlighted as essential to make robotic systems more accessible and easier to use.

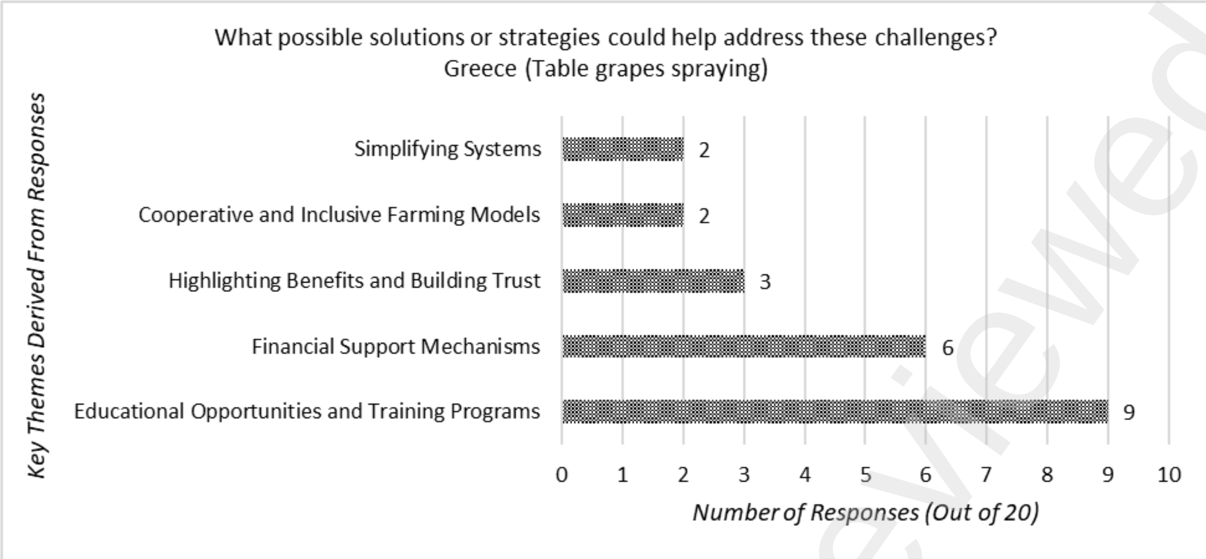



*Figure 20. Solutions in Market Adoption identified by Greek Participants*

**Suggestions for Improvement**

**France**

The thematic analysis of 20 responses from participants in France highlighted two primary suggestions for enhancing future demonstration events on robotic farming technologies (Figure 21). The most frequently mentioned suggestion was **Interactive and Hands-On Engagement** (15 mentions). Participants consistently emphasised the need for more interactive demonstrations, with responses like "interactive" and "more interactive" underscoring the importance of practical engagement. This suggests that allowing attendees to actively participate in or observe real-time operations of robotic systems would greatly improve the effectiveness of these events. The second theme, cited by 5 participants, was the need for **Presenting Research Results and User Testing**. Participants expressed interest in seeing more detailed results from studies related to the demonstrated technologies, as well as opportunities for extended user testing. Comments such as "present more results of studies" and "more user testing" reflected a desire for access to concrete data and evaluations of the technologies over time.

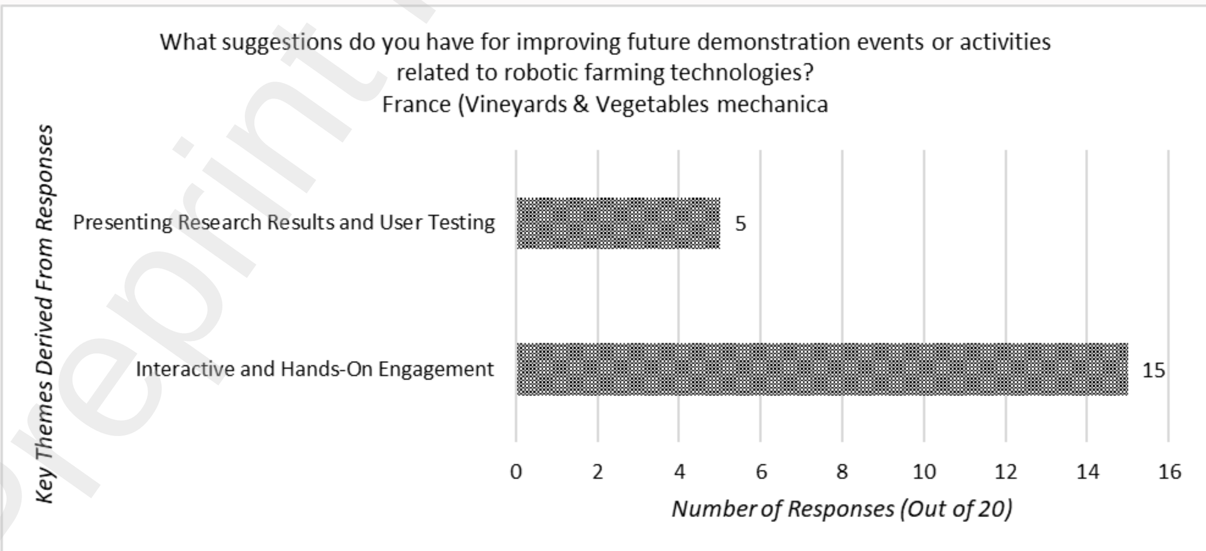



*Figure 21. Suggestions for SUD Improvement identified by French Pilot*

**The Netherlands**

The thematic analysis of 20 responses from participants in the Netherlands highlighted two dominant suggestions for improving future demonstration events on robotic farming technologies, with an additional emphasis on educational opportunities (Figure 22). The most frequently suggested improvement was **Interactive and Hands-On Engagement** (10 mentions). Participants repeatedly advocated for more opportunities to directly interact with the robotic systems, citing the need for "hands-on experiences." This reflects a strong interest in practical engagement to allow farmers to better understand and evaluate the technologies. Another significant theme was **Expanding Demonstrations and Applications** (8 mentions). Respondents suggested showcasing a wider variety of applications for robotic systems, with comments like "show more applications and demonstrations" indicating a desire for demonstrations that go beyond the current focus on potato weeding. A smaller but notable theme was **Educational Sessions** (2 mentions). Participants recommended integrating seminars and demonstrations to provide both theoretical knowledge and practical exposure, ensuring farmers can effectively learn about the technologies and their benefits.

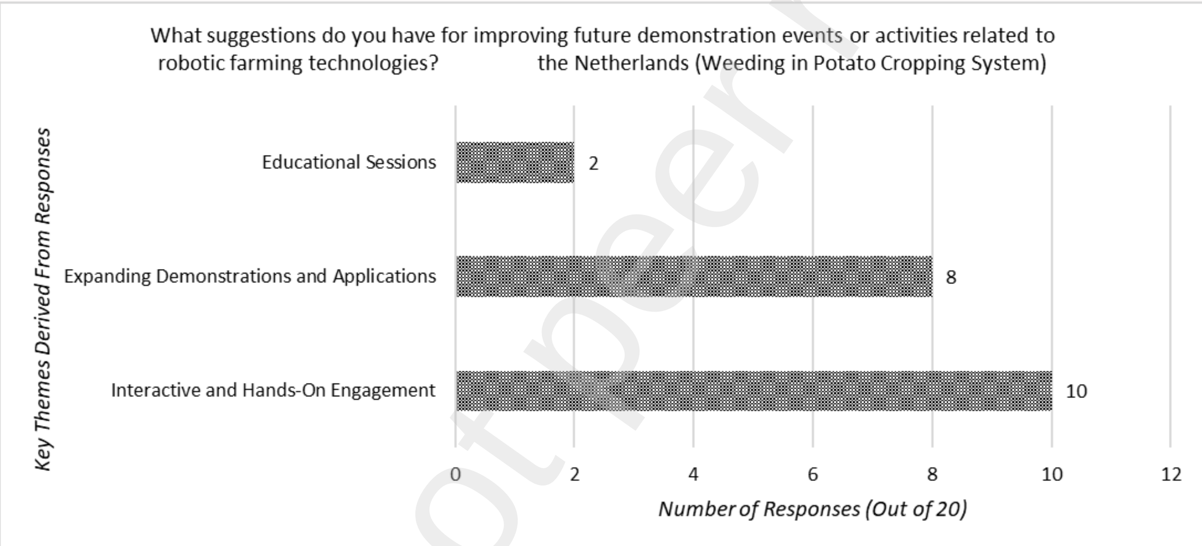



*Figure 22. Suggestions for SUD Improvement identified by Dutch Pilot*

**Spain**

The thematic analysis of 44 responses from participants in Spain revealed several key suggestions for improving future demonstration events on robotic farming technologies (Figure 23). The most frequently suggested improvement was **Interactive and Hands-On Engagement** (16 mentions). Participants emphasised the importance of providing farmers with opportunities for hands-on experiences, such as "real-time demonstrations" and "test drives for farmers." These suggestions highlight the need for practical engagement to familiarise participants with the robotic systems. **Educational Efforts and Seminars** (15 mentions) also emerged as a significant theme. Respondents recommended hosting more seminars, presentations, and online or real-time educational sessions to address knowledge gaps and improve understanding of the technologies, particularly among farmers. **Field Experts and Expert Interaction** (7 mentions) were frequently mentioned as essential for effective demonstrations. Participants suggested involving "field experts" to guide and support farmers, ensuring that the demonstrations provide expert-led insights and practical assistance. **Real-Time Presentations and Demonstrations** (5 mentions) were highlighted as valuable additions to the events, with respondents advocating for live showcases that allow farmers to observe the technologies operating in real-world conditions. Several participants also suggested **Technology Expansion Beyond Spraying** (4 mentions), expressing interest in demonstrations showcasing additional applications beyond spraying, such as other treatments or operations. Lastly, **Simplified Materials and Constant Updates** (3 mentions) were proposed to support farmers after demonstrations. Suggestions included creating "simple user manuals" and providing "constant updates" on technological advancements to ensure ongoing learning and support.

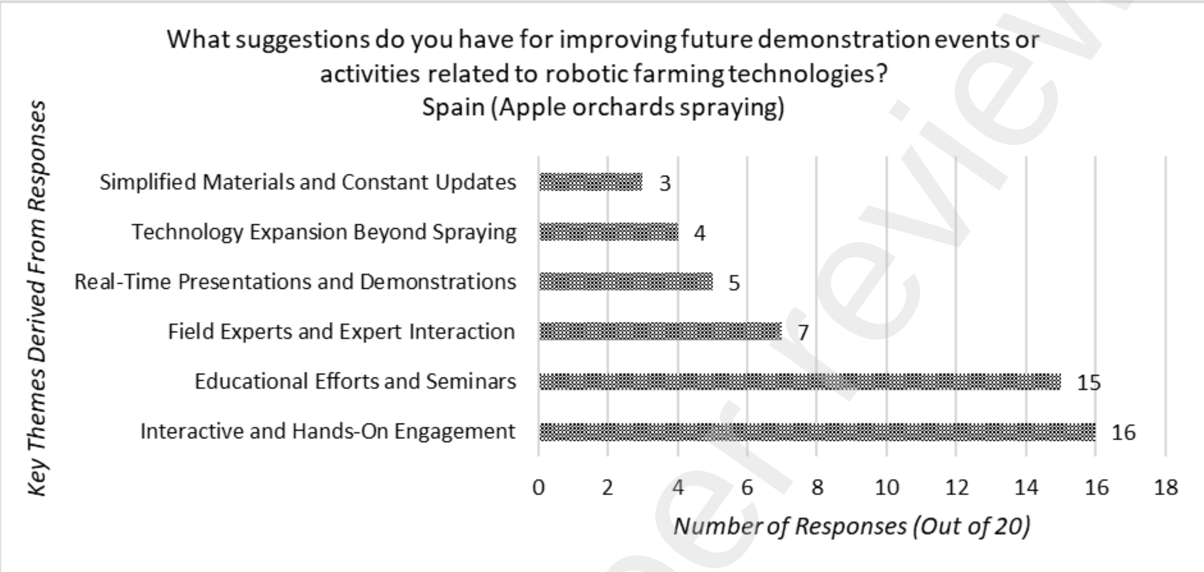



*Figure 23. Suggestions for SUD Improvement identified by Spanish Pilot*

**Greece**

The thematic analysis of 20 responses from participants in Greece highlighted several key suggestions for improving future demonstration events on robotic farming technologies (Figure 24) The most frequently suggested improvement was **Interactive and Hands-On Engagement** (8 mentions). Participants advocated for demonstrations that allow direct interaction with the robotic systems, such as opportunities to control or observe the technologies in real-time. They also suggested incorporating more interactive presentations to enhance participant engagement. **Educational Opportunities and Expert Interaction** (6 mentions) also emerged as a significant theme. Respondents recommended offering short training sessions to teach attendees how to operate, maintain, and troubleshoot robotic systems. Additionally, they suggested creating opportunities for attendees to engage directly with experts and early adopters of the technology, facilitating a deeper understanding and practical knowledge transfer. Another key suggestion was providing **Detailed Presentations and Specialised Information** (4 mentions). Participants emphasised the need for presentations that focus on real-world challenges, such as cost, maintenance, and return on investment (ROI). Hosting panel discussions and offering exclusive presentations tailored to farmers' specific needs were also suggested. Lastly, participants highlighted the importance of **Supplementary Materials and Comprehensive Testing** (2 mentions). Suggestions included distributing printed guides on the demonstrated technologies and presenting results from long-term testing, such as evaluations over an entire growing season.

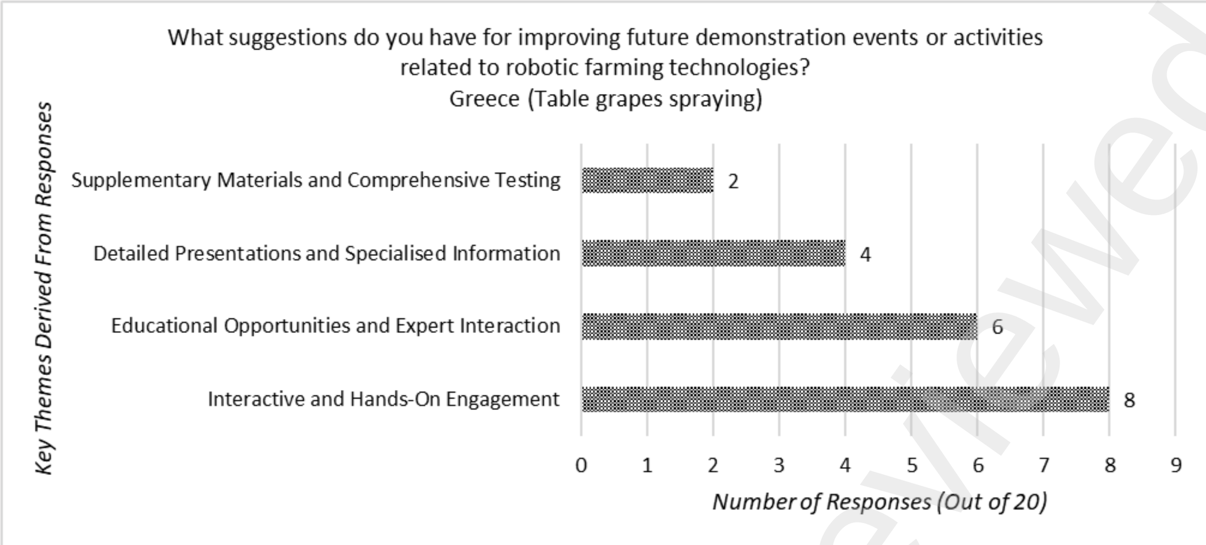



*Figure 24. Suggestions for SUD Improvement identified by Greek Pilot*

### 3.2. Results from feedback analysis during FC & DT SUDS to Students

**Familiarity and Understanding of Technologies**

The survey results on participants' familiarity with digital farming tools, such as Digital Twins and the Farming Controller, revealed a general lack of prior knowledge among respondents. Only 3.7% of participants rated their familiarity as 4/5, indicating above-average expertise. Meanwhile, 25.9% of respondents rated their familiarity as 2/5 or 3/5, reflecting a moderate understanding. The majority, 70.4%, rated their familiarity as 1/5, signifying minimal prior exposure to these technologies (Figure 25).

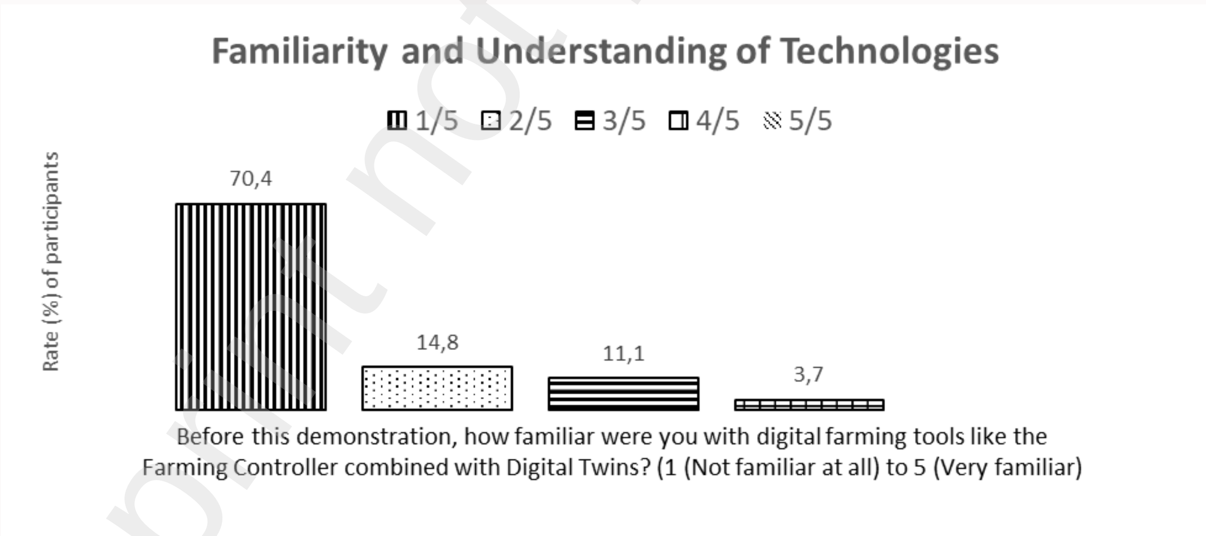



*Figure 25. Feedback for Familiarity and Understanding of Technologies - Bar Chart*

**Demonstration Impact and Perception**

The survey findings reveal that 94.4% of students reported an improved understanding of how the Farming Controller functions in conjunction with Digital Twins. A small percentage, 3.7%, indicated no change in their knowledge, while 1.9% reported feeling more confused following the demonstration (Figure 26).

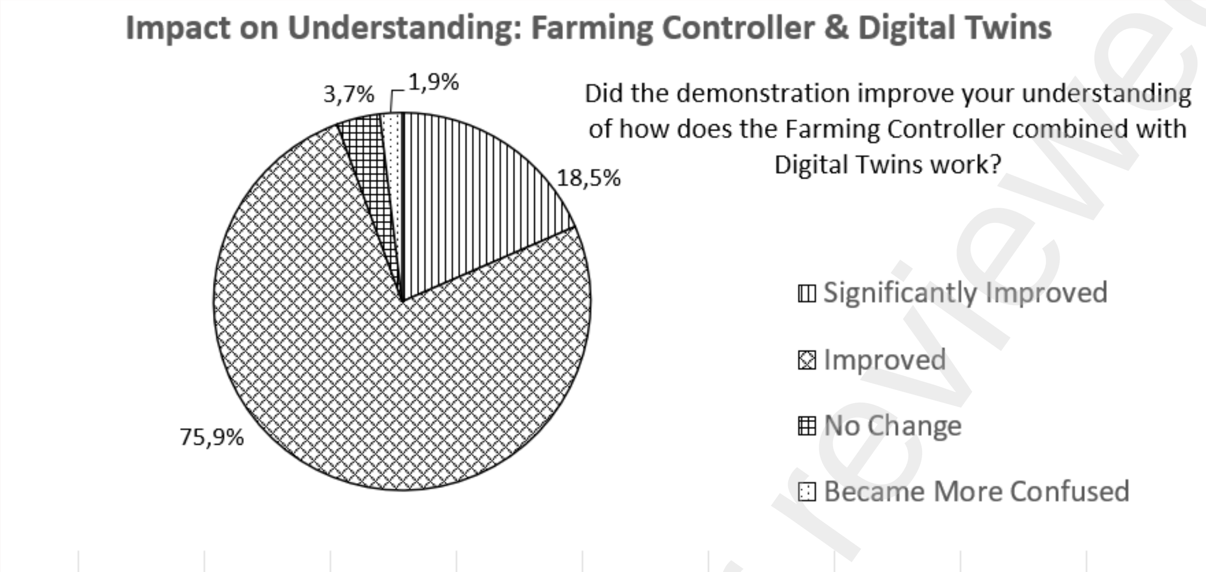



*Figure 26. Feedback for Impact on Understanding: Farming & Digital Twins- Pie Chart*

In terms of perception, 81.4% of respondents expressed the belief that the Farming Controller combined with Digital Twins will play a crucial role in the future of agriculture. Additionally, 14.8% of participants provided a moderate response, recognising the technology's potential but with some reservations, while 3.7% viewed it less favourably (Figure 27).

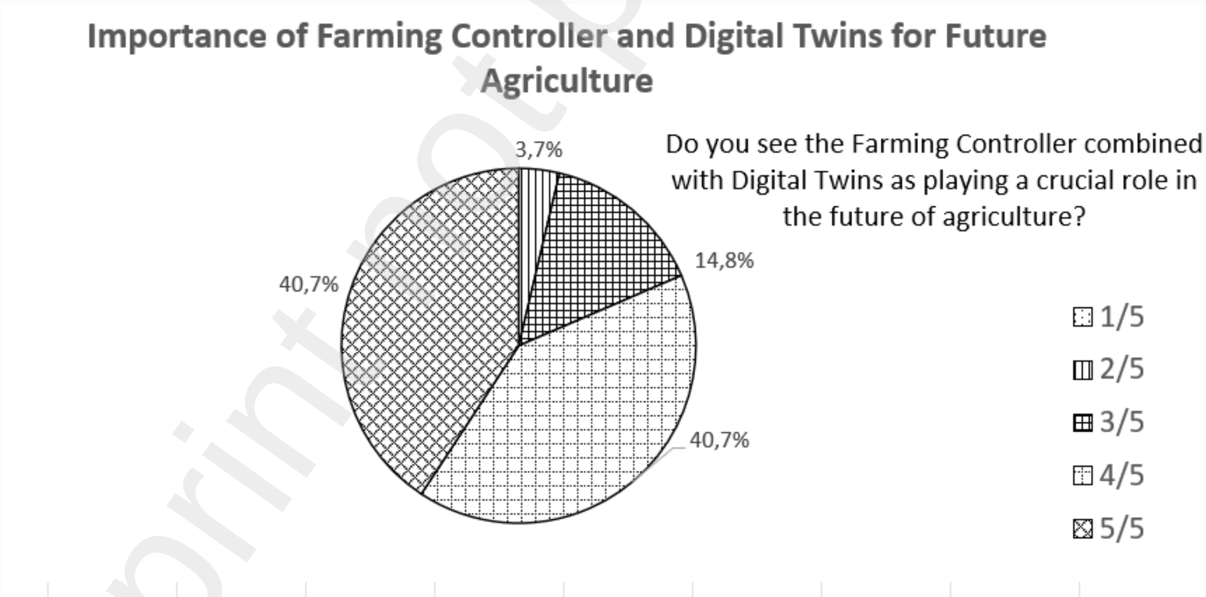



*Figure 27. Feedback for the Importance of Farming Controller and Digital Twins for Future Agriculture- Pie Chart*

**Interactive Experience and Further Interest**

Students were asked to rate whether incorporating more opportunities to interact with the equipment would make the demonstration more engaging or educational. The findings indicate that 75.9% of participants believe that an interactive experience, such as setting up a task or mission, would significantly enhance their interest in the demonstration. Meanwhile, 18.5% were neutral on the matter, and 5.6% expressed negative views, rating the idea 2/5 (Figure 28).

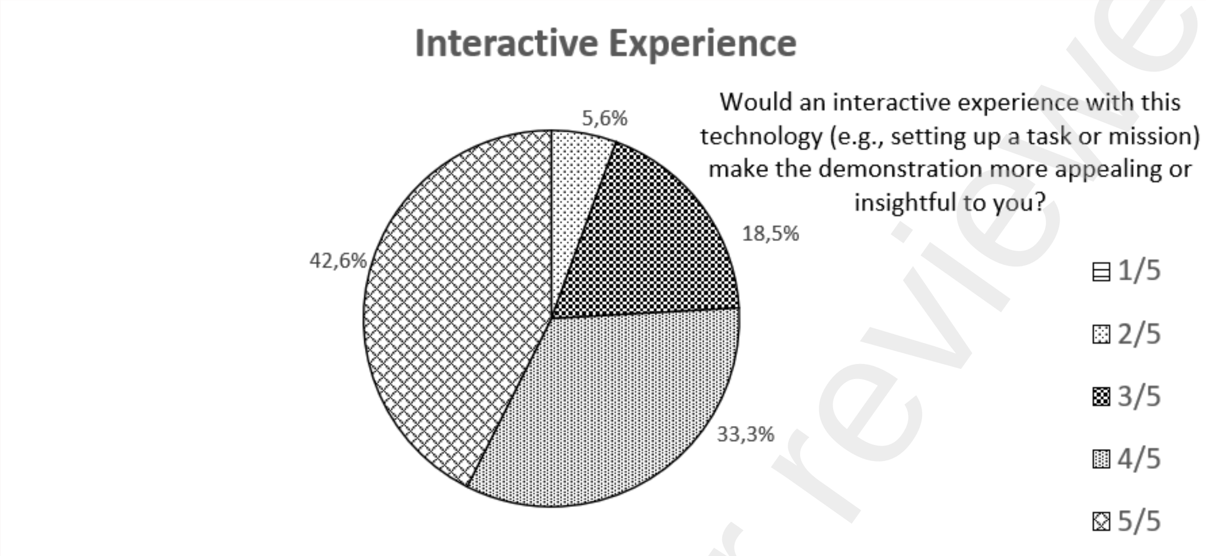



*Figure 28. Feedback regarding the Interactive Experience -Pie Chart*

In addition, students were asked whether they would be interested in a more in-depth course or training material focusing on these technologies and their practical applications. Enthusiasm was evident, with 20.4% of respondents expressing a strong interest. Another 40.7% were neutral, indicating that they might be open to additional training with the right incentives or context, while 14.9% expressed little to no interest (Figure 29).

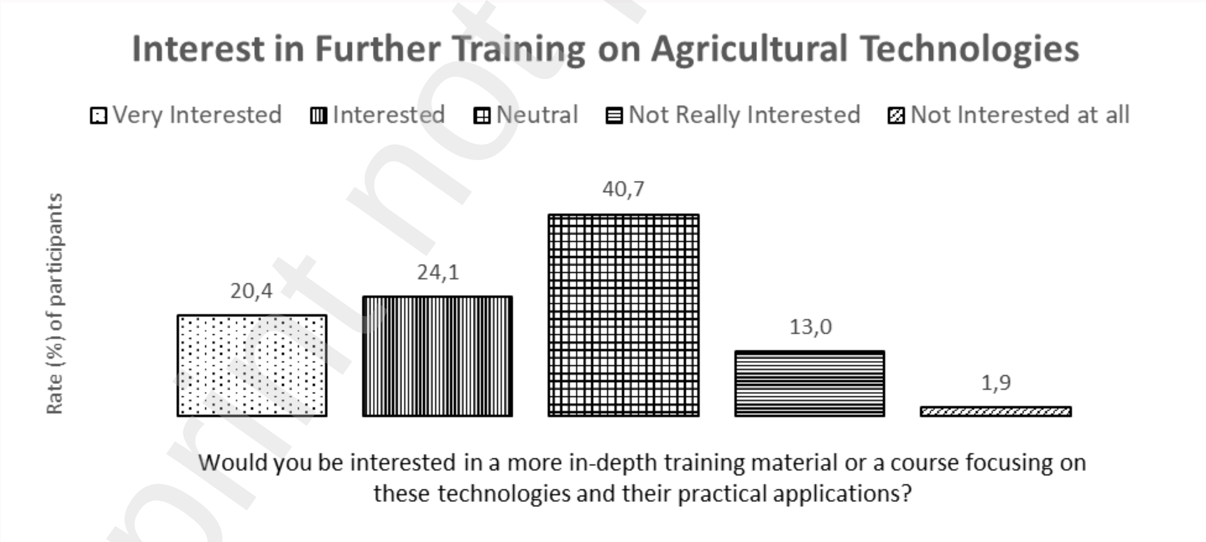



*Figure 29. Feedback regarding the Interest in Further Training on Agricultural Technologies -Bar Chart*

**Enthusiasm and User-Friendliness**

Participants were asked to rate their enthusiasm about using the Farming Controller and Digital Twins technologies in their future agricultural careers. The results indicate that 44.4% of respondents expressed moderate to no enthusiasm, rating their excitement as 1 or 2 while 20.4 % gave a rate of 4 or 5 and 35.2 % a rate of 3. (Figure 30).

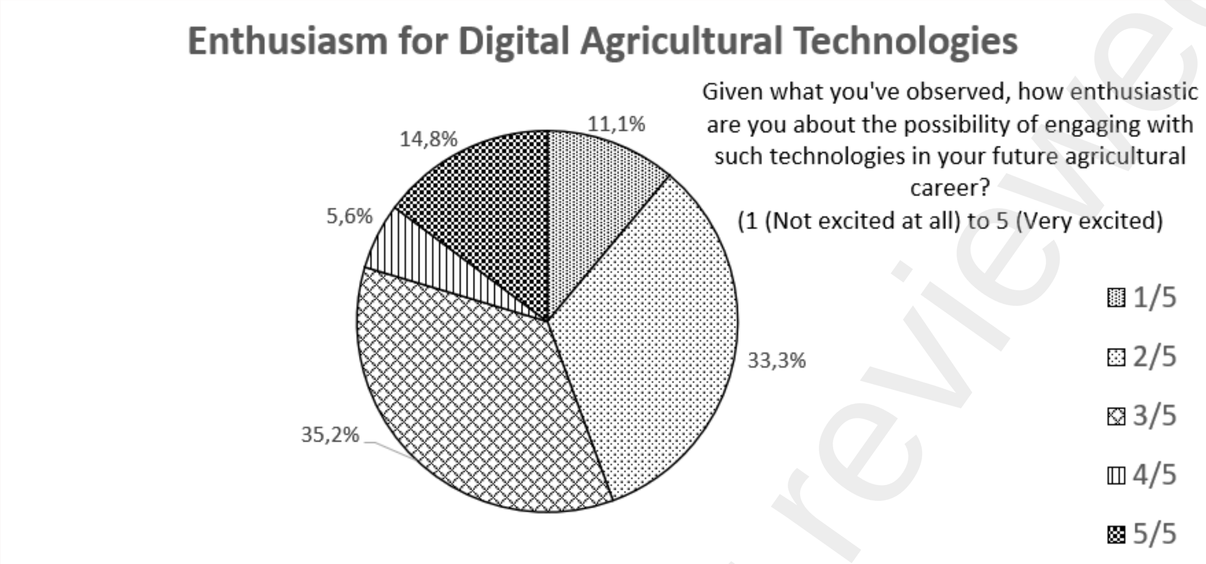



*Figure 30. Feedback regarding Enthusiasm for Agricultural Technologies - Bar Chart*

When evaluating the user-friendliness of the Farming Controller and Digital Twins technologies based on the demonstration, the majority of respondents provided positive ratings with only 9.3% of them rating the technology poorly for user-friendliness (Figure 31).

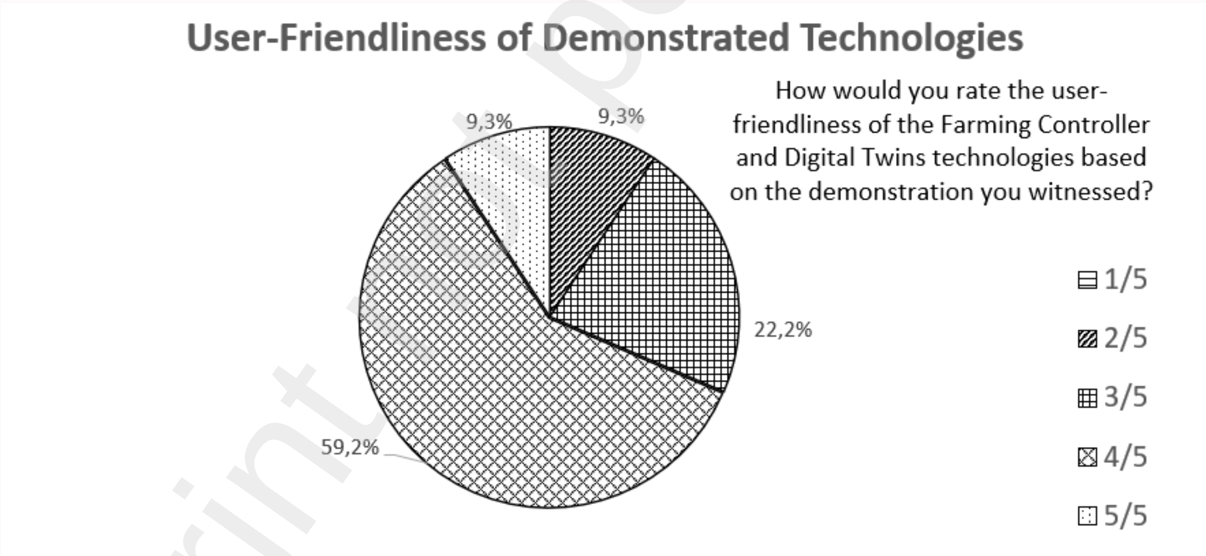



*Figure 31. Feedback regarding User-Friendliness of Demonstrated Technologies – Pie Chart*

**Benefits, Challenges, and Enhancements**

The thematic analysis of 54 student responses to open-ended questions identified key themes concerning the benefits and challenges of integrating the Farming Controller with Digital Twins in modern farming, as well as proposed enhancements for improving communication and engagement in demonstration events.

During the demonstration, participants were invited to highlight the benefits of integrating the Farming Controller with Digital Twins that most appealed to them, and the thematic analysis of the results identified eight key themes (Figure 32). **Increased Efficiency** (27 mentions) emerged as the most prominent theme, with students emphasising the potential to streamline operations, improve productivity, and achieve outcomes such as "faster farming" and "maximisation of results." **Smart Automation** (20 mentions) closely followed, with responses highlighting enhanced robot performance, including their ability to "design precise agricultural operations" and "reduce the need for human intervention." **Cost and Labour Reduction** (18 mentions) reflected the perceived economic benefits, including "reduced operational costs" and "less manual labour." Similarly, **Simulation and Support** (15 mentions) captured the value of predictive tools, enabling students to envisage scenarios such as "test runs before entering the field" or "offering recommendations for appropriate solutions." Environmental considerations featured in **Eco-Friendly Farming** (10 mentions) and **Reduced Chemical Input** (9 mentions), where students recognised the potential to "cultivate without toxic pesticides" and minimise environmental harm. **Crop Safety** (7 mentions) focused on protecting crops from damage through advanced systems, while **Local Tech Progress** (7 mentions) highlighted the regional benefits of developing technologies, such as the "development of agricultural robots in Greece" and opportunities to modernise the agricultural workforce. Students acknowledged that such progress enhances Greece's competitiveness in the agricultural sector, fosters local expertise, and creates opportunities for research and workforce development.

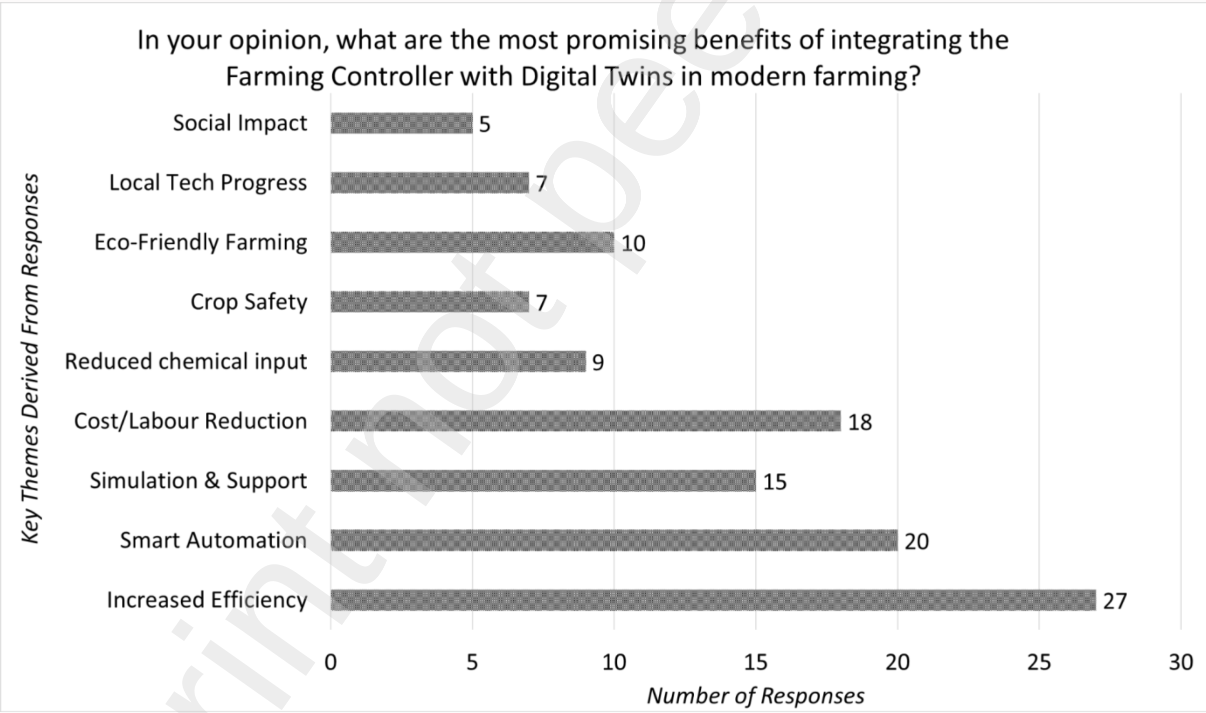



*Figure 32. Feedback on FC & DT integration to modern farming- Bar Chart*

Participants were then asked to identify potential challenges to the widespread adoption of digital agricultural technologies (Figure 33). The most frequently mentioned challenge, **Knowledge Gaps and Technical Expertise** (31 mentions), highlighted the lack of knowledge and training among agricultural professionals in using advanced technologies. Students noted issues such as "difficulty understanding the operation of these technologies" and the absence of "training programs to enhance user skills." **Financial Barriers** (17 mentions) emerged as the second most prominent challenge, with responses emphasising the high initial costs of equipment, "funding challenges for smaller farms," and "economic inaccessibility." Additionally, **Operational Challenges** (10 mentions), including "complexity of technology interfaces" and "reliability concerns," underscored the need for user-friendly systems and robust testing protocols. Other challenges included **Resistance to Change** (6 mentions), where students described scepticism among professionals, particularly older farmers, towards adopting new methods, often due to a "preference for traditional farming techniques." **Infrastructure Issues** (3 mentions) were also noted, with mentions of "connectivity problems in rural areas" impeding technology adoption. Lastly, **Environmental Issues** (2 mentions) such as "weather conditions" and "energy consumption" were perceived as barriers to operational efficiency.

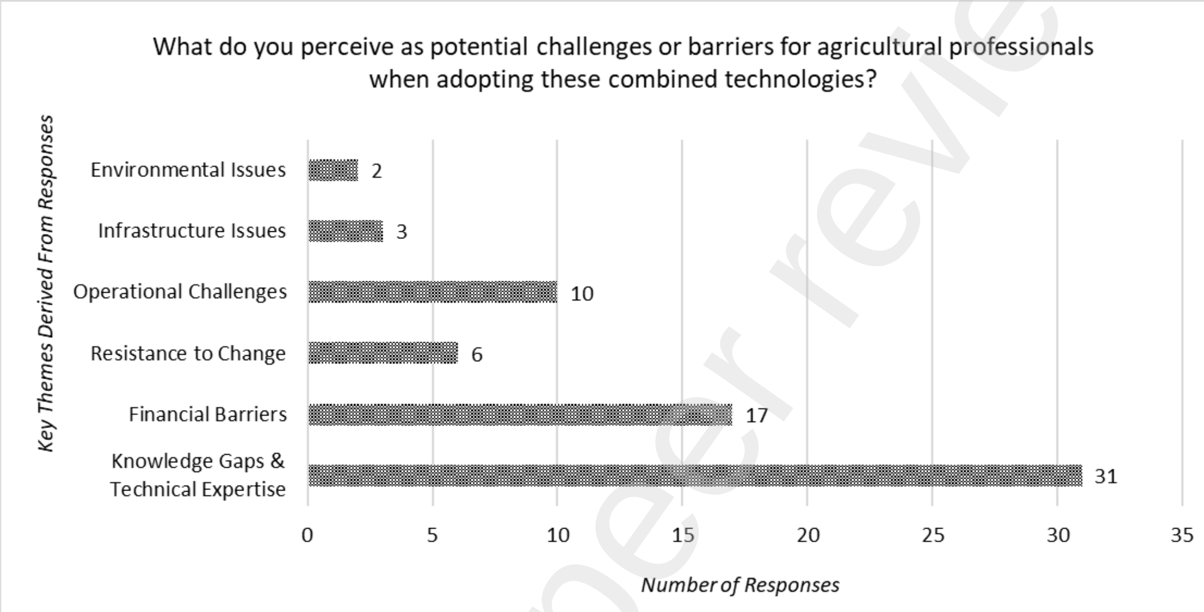
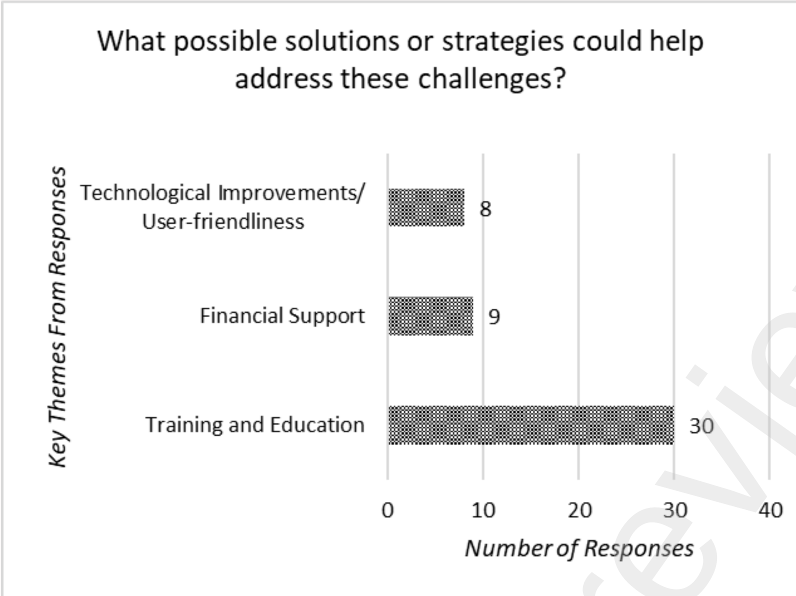



*Figure 33. Feedback on challenges towards adoption of FC & DT - Bar Chart*

In terms of proposed solutions (Figure 34), the most frequently cited strategy was **Training and Education** (30 mentions), including the organisation of "seminars and workshops," pairing older professionals with "younger, tech-savvy farmers," and sharing "success stories" to build trust and engagement. **Financial Support** (9 mentions), such as "subsidies and funding from public authorities" and "financial assistance for smaller farms," was identified as a crucial enabler for widespread adoption. Finally, **Technological Improvements** (8 mentions), including "simplifying technology interfaces" and "ensuring reliability through testing," were highlighted as necessary steps to minimise the learning curve and improve user confidence.

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654 *Figure 34. Feedback on solutions to overcome challenges towards adoption of FC & DT - Bar Chart*

655 Finally, participants offered suggestions for improving future demonstration events, identifying five key themes (Figure 35). The most frequently mentioned theme, **Interactive and Hands-On Engagement** (34 mentions), underscored the importance of active participation and practical experiences. Students suggested opportunities to "use the application and run simulations," "participate in interactive activities," and even "gamify the presentation" to make the demonstrations more dynamic and engaging. This was followed by **Real-Life and Practical Applications** (13 mentions), which emphasised showcasing "live data streams from actual farms," sharing "feedback from farmers implementing such technologies," and presenting "real-life application videos" to provide relatable, context-driven examples. **Student Involvement** (7 mentions) highlighted the value of integrating students' experiences, such as having "student presenters with experience using the technology" and enabling them to lead projects or open-field demonstrations. Similarly, **Detailed Resources and Training Opportunities** (7 mentions) called for more in-depth educational materials, including "a course on these technologies," "comprehensive breakdowns of agricultural concepts," and "detailed presentations to understand topics more thoroughly." Lastly, **Tailored and Inclusive Presentations** (7 mentions) addressed the need for presentations to align with students' varying levels of interest and knowledge, suggesting that demonstrations should be "more relatable to students' interests."

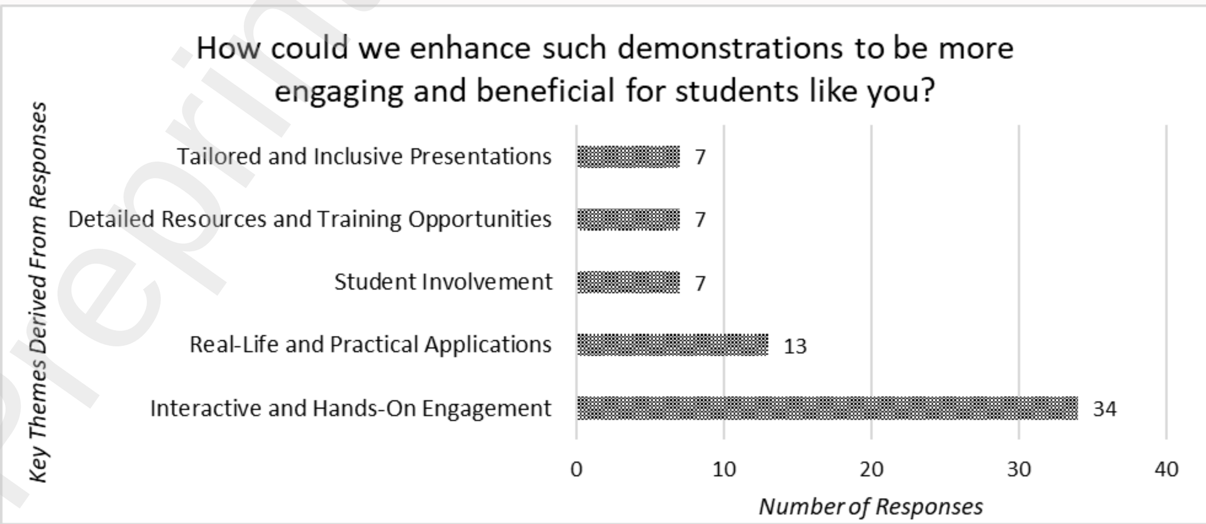


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*Figure 35. Feedback on suggestions for improving future demonstration - Bar Chart*

# 4. Discussion

## 4.1. SUDs in Four R4C Countries

**Participant Background and Affiliation**

The composition of participants in the R4C project demonstrations varied across the four countries, reflecting regional differences in stakeholder engagement and interests. In France and the Netherlands, where SUDs focused on mechanical weeding technologies, farmers constituted the majority of attendees (80% and 90%, respectively). This high level of farmer participation suggests a strong interest in practical solutions that directly address operational challenges in these regions. In contrast, the SUDs in Greece and Spain, which showcased autonomous spraying systems, attracted a more diverse audience. Farmers made up 65% of participants in Greece and 72.7% in Spain, with the remaining attendees representing academia, regulatory bodies, and other roles. This diversity indicates a broader interest in the environmental, regulatory, and technical aspects of spraying technologies. The variation in audience composition underscores the importance of tailoring demonstration activities to the specific needs and interests of different stakeholder groups. For instance, farmer-centric events might focus on hands-on applications and immediate practical benefits, while demonstrations with a more diverse audience could address regulatory frameworks, technical specifications, and broader implications of the technology.

Engaging a wide range of stakeholders is crucial for the successful adoption of agricultural innovations. A study by Dessart et al. (2019) emphasises that early and continuous engagement of stakeholders is essential for sustainable, desirable, and acceptable innovation in agriculture. Their research highlights the need for inclusive approaches that consider the perspectives of various actors, including farmers, advisors, researchers, and policymakers. Understanding the composition of participants and their affiliations is vital for designing effective demonstration activities. By considering the specific interests and needs of different stakeholder groups, organisers can enhance engagement, facilitate knowledge exchange, and ultimately promote the adoption of innovative agricultural technologies.

**Evaluation of Demonstration Activities**

The evaluation of demonstration activities across the four countries indicates a predominantly positive reception, with over 80% of participants rating the demonstrations 4 out of 5 or higher. This suggests that the demonstrations were effective in engaging stakeholders and conveying the intended information. In Spain, 40.9% of participants awarded a perfect score of 5 out of 5, reflecting a high level of satisfaction. This positive feedback may be attributed to the demonstrations' relevance to local agricultural practices and the clarity with which the technologies were presented. Similarly, in Greece, 45% of participants rated the activities as excellent, indicating that the demonstrations resonated well with the audience. The Netherlands also received strong approval, with 80% of participants giving positive ratings. The absence of negative ratings (1/5 or 2/5) underscores the demonstrations' success in meeting participants' expectations. In France, 85% of participants rated the demonstrations 4 out of 5 or higher, highlighting the overall effectiveness of the activities.

These findings align with existing literature emphasising the importance of well-structured on-farm demonstrations in facilitating effective learning and technology adoption among farmers. Pappa et al. (2018) highlight that on-farm demonstrations allow farmers to observe new technologies in a real-world setting, interact with experts, and clarify doubts, thereby enhancing their learning experience. Furthermore, the success of these demonstrations can be linked to the participatory approach employed, which involves stakeholders in the planning and execution of the activities. Ingram et al. (2021) discuss how embedding demonstration programmes within existing agricultural advisory services and adapting to local contexts through collaboration and networking can enhance their effectiveness.

To build on this success, future demonstration activities should consider tailoring content to local needs by customising demonstrations to address specific local challenges and farming practices, thereby enhancing relevance and engagement. Enhancing interactivity through the incorporation of elements such as hands-on sessions and real-time problem-solving can further improve participant involvement and satisfaction. Strengthening follow-up support by providing ongoing resources and assistance post-demonstration can aid participants in the practical implementation of new technologies. By adopting these strategies, future demonstration activities can continue to effectively inform and engage farmers, advisors, researchers, policymakers, tech companies, and other stakeholders, thereby promoting the adoption of innovative agricultural practices.

**Factors Influencing Attendance**

The analysis of factors influencing attendance at demonstration activities across the four countries reveals a predominant interest in robotic farming technologies, with 60% to 86% of participants citing it as their primary motivator. This widespread enthusiasm underscores a global curiosity about technological advancements in agriculture.

However, regional variations in secondary motivations provide deeper insights. In France, 60% of participants highlighted the potential impact on their professional practices, and 45% were influenced by recommendations from colleagues or industry experts. This suggests that both practical considerations and peer influence play significant roles in decision-making. Similarly, in the Netherlands, 40% of respondents were motivated by potential professional impacts, though only 10% cited peer suggestions, indicating a more individualistic approach to adopting new technologies.

In Spain, while 86.4% were driven by an interest in robotic technologies, 47.7% attended to learn more about the R4C project, reflecting effective project outreach. Conversely, in Greece, motivations were more evenly distributed: 40% were interested in robotic technologies, another 40% in the R4C project, and 35% in potential professional impacts. This balance suggests a multifaceted approach to engagement, where both technological curiosity and project-specific information are equally valued.

These findings align with existing literature emphasising the importance of practical demonstrations and peer influence in technology adoption. Field demonstrations have been shown to effectively raise awareness and encourage the adoption of new agricultural practices by providing hands-on experiences that bridge the gap between research and practical application. Additionally, studies indicate that peer recommendations and social networks significantly influence farmers' decisions to adopt new technologies, as they provide trusted sources of information and validation (Patii et al., 2017; Kinyangi, 2014). Research on the diffusion of innovations highlights that opinion leaders within a community can accelerate the adoption process by endorsing new practices, thereby leveraging existing social structures to facilitate change (Kinyangi, 2014).

Understanding these regional nuances is crucial for stakeholders (farmers, advisors, researchers, policymakers, and tech companies) to tailor their communication and engagement strategies effectively. For instance, in regions where peer influence is strong, leveraging local champions or early adopters to advocate for new technologies could enhance participation. In areas with a balanced set of motivations, providing comprehensive information that addresses both technological aspects and project-specific details may be more effective. While a universal interest in robotic farming technologies drives attendance at demonstration activities, acknowledging and addressing regional differences in secondary motivations can lead to more targeted and effective engagement strategies, ultimately facilitating the adoption of innovative agricultural practices.

**Familiarity and Understanding of Robotic Farming**

The survey results reveal varying levels of familiarity with robotic farming technologies across the four countries, reflecting regional differences in exposure and adoption of such innovations. In the Netherlands, 50% of participants reported high familiarity (4/5 or 5/5), aligning with the country's leadership in precision agriculture and early adoption of advanced farming practices. This aligns with broader trends observed in technologically advanced agricultural regions, where the integration of innovative solutions like robotic systems is supported by established infrastructures and policies encouraging digital farming (Tamirat et al., 2023).

In contrast, France, Greece, and Spain exhibited a broader spectrum of familiarity, with the majority of participants rating their knowledge at moderate levels (2/5 to 4/5). This diversity in baseline knowledge reflects varying stages of digital transformation in these countries' agricultural sectors. Factors such as limited access to cutting-edge technologies, differing levels of government support, and regional farming practices may contribute to these variations. Despite these disparities, the demonstrations proved effective in engaging participants across the spectrum of familiarity.

Despite these initial differences, the demonstrations effectively enhanced participants' understanding of robotic farming across all countries. Positive feedback ranged from 80% in the Netherlands to 100% in Spain and Greece, underscoring the value of hands-on demonstrations in bridging knowledge gaps. This finding is consistent with studies highlighting the effectiveness of field demonstrations in increasing technology adoption among farmers (Emerick & Dar, 2021). By allowing participants to observe technologies in action and interact with experts, these events offer a tangible understanding of how innovations can be integrated into existing farming systems.

The remaining 10% to 20% of participants who did not report improved understanding suggest opportunities for refining these demonstrations. Tailoring content to address varying levels of expertise, simplifying technical explanations, and providing supplementary materials could enhance engagement and comprehension. For example, introducing pre-demonstration materials tailored to beginner, intermediate, and advanced audiences might better prepare participants to engage with the content. Such targeted approaches are crucial, as familiarity with technology is a significant driver of adoption (Tamirat et al., 2023).

In regions with higher baseline familiarity, like the Netherlands, demonstrations could focus on advanced features and integration with existing systems. This could include showcasing the scalability of robotic farming solutions and their compatibility with precision farming practices already in use. Conversely, in countries with moderate familiarity, foundational education emphasizing practical applications and step-by-step guidance may be more beneficial. Providing clear examples of the cost-efficiency and environmental benefits of robotic farming technologies could resonate strongly with these audiences. This strategy aligns with the need for effective extension methods to raise awareness and stimulate the adoption of new technologies among farmers (Mustapha, 2017).

Overall, while the demonstrations successfully enhanced understanding of robotic farming technologies, future efforts should continue to adapt content to regional differences and audience needs. By addressing the specific barriers and opportunities in each region, organisers can ensure broader and more effective dissemination of these innovations, ultimately fostering greater acceptance and utilisation of robotic farming systems.

### Quality of Information and Perception Change

The feedback from participants across the four countries indicates a generally positive reception to the quality of information presented during the demonstrations, with most participants rating their experience as 4/5 or higher. This consistent trend underscores the effectiveness of the demonstrations in delivering relevant and high-value content to a diverse audience of stakeholders.

In France, 80% of participants reported a positive shift in their perception of robotic farming technologies, with the demonstrations highlighting practical benefits such as labour reduction, 24-hour operational capacity, and improved productivity. These benefits align with the specific needs of vineyard farmers, who face labour-intensive tasks requiring precision and reliability. The strong emphasis on operational efficiency and environmental sustainability further resonated with the audience, reflecting their interest in sustainable farming practices.

Similarly, Greece demonstrated a transformative impact, with 100% of participants reporting an enhanced understanding of the technologies and their benefits. The feedback highlighted cost reduction, efficient resource use, and enhanced safety as key advantages, particularly relevant for the spraying technologies showcased. The use of accessible explanations and real-time decision-making examples through the Farming Controller resonated well with the audience, addressing the practical challenges faced by Greek farmers in managing spraying operations effectively.

Spain also received overwhelmingly positive feedback, with 88.6% of participants affirming a change in their perception of robotic farming's potential benefits. Participants praised the precision application capabilities of the retrofitted tractor and the associated reduction in labour and chemical inputs. These advantages align with the priorities of orchard farmers in Spain, where improving production efficiency while maintaining sustainability is a key concern. However, a small percentage of participants expressed reservations, suggesting that targeted engagement efforts are necessary to address lingering doubts and build broader trust in these technologies.

Conversely, the Netherlands exhibited a more nuanced response. While 80% of participants rated the quality of information highly, 40% expressed doubts about the benefits of robotic farming. This mixed perception suggests that the information provided, while thorough, may not have been fully convincing to all attendees. Factors such as the complexity of the technology or concerns about cost-effectiveness in smaller-scale operations may have influenced this response. The results highlight the need for more practical examples, such as long-term data and case studies, to demonstrate the tangible impact of these technologies in the Dutch context, where adoption barriers may differ.

The variation in perceptions across countries emphasizes the importance of tailoring demonstration strategies to regional contexts and stakeholder priorities. While some regions may prioritize environmental benefits and safety, others may require a stronger focus on economic feasibility and operational integration. Addressing these nuanced requirements through immersive demonstrations and evidence-based examples can enhance the effectiveness of future outreach efforts and foster greater acceptance of robotic farming technologies across diverse agricultural landscapes.

These findings align with existing literature on technology adoption in agriculture. For instance, a study on farmers' perceptions of precision agriculture technology benefits found that perceived usefulness and ease of use significantly influence adoption decisions (Thompson et al., 2019). Additionally, research on the adoption of agricultural technology in the developing world highlights the importance of addressing farmers' specific needs and concerns to facilitate technology uptake (Ruzzante et al., 2021). These studies underscore the critical role of perceived usefulness and ease of use in technology adoption. When farmers find a technology beneficial and user-friendly, they are more likely to embrace it. This is particularly relevant to our findings, where participants across various countries reported enhanced understanding and positive perception changes following the demonstrations. The practical exposure provided by these demonstrations likely contributed to increased perceived usefulness and ease of use, thereby facilitating a more favourable attitude towards robotic farming technologies.

Moreover, addressing specific needs and concerns is vital for successful technology adoption. The demonstrations tailored to regional contexts and stakeholder priorities, as observed in our study, resonate with this principle. By focusing on locally relevant applications and challenges, the demonstrations effectively engaged participants, leading to a positive shift in perceptions. This approach aligns with Ruzzante et al.'s (2021) emphasis on the necessity of context-specific strategies to promote technology uptake in agriculture. Overall, the alignment of our findings with existing literature highlights the importance of perceived usefulness, ease of use, practical exposure, and addressing specific needs in promoting the adoption of agricultural technologies. Future initiatives should continue to incorporate these elements to enhance the effectiveness of demonstrations and facilitate the broader acceptance of innovative farming practices.

**Challenges and Solutions in Market Adoption**

The adoption of robotic farming technologies encounters several challenges, as identified across the four countries surveyed. High initial costs consistently emerged as a significant barrier, with participants from France, Greece, Spain, and the Netherlands highlighting the financial strain posed by these technologies. This concern is echoed in the literature, where high initial investment costs are noted as a primary obstacle to ag-tech adoption, particularly for small and medium-sized farms (Rial-Lovera, 2018). To mitigate these financial challenges, participants recommended subsidies, financial support mechanisms, and cooperative farming models, underscoring the necessity of financial planning and institutional backing to drive adoption.

In addition to financial barriers, a lack of technical knowledge among farmers, especially among older generations, was highlighted as a significant impediment. This aligns with findings that emphasise the need for user-centred design strategies and comprehensive training programs to enhance technology adoption in rural areas (Talero-Sarmiento et al., 2023). Participants advocated for targeted educational initiatives, including training seminars and practical demonstrations, to empower farmers with the necessary skills and confidence to operate and maintain these systems effectively.

Scepticism and resistance to change further complicate adoption efforts. Building trust through informative seminars and showcasing the long-term benefits of robotic farming technologies are essential strategies to address these concerns. The importance of effective communication strategies in boosting the adoption of valuable agricultural technologies has been underscored in recent studies (Devitt, 2021).

Legislative constraints, particularly regarding the regulation of autonomous systems, were also noted as challenges. Clear and supportive legislation is essential to facilitate the integration of these technologies. Addressing regulatory barriers through collaborative efforts between policymakers, technology developers, and farmers can promote the adoption of robotic systems in agriculture (EU, 2023).

Data privacy concerns, specifically in the Netherlands, highlight the need for robust data protection measures and transparent policies. Providing farmers with control over their data can help build trust and ensure a smoother adoption process. The significance of data ownership and use in the adoption of robotic technologies in agriculture has been discussed in the literature (Kutter et al., 2011; Rial-Lovera, 2018).

Finally, concerns about the replacement of manual labour with robotic solutions were expressed, particularly in France and the Netherlands. Emphasising how these technologies can complement rather than replace human labour, and showcasing success stories, may help alleviate these fears. The potential impact of automation on labour in agriculture has been explored in recent studies, highlighting the need for balanced integration strategies. For instance, Acemoglu and Restrepo (2020) found that while automation can displace certain jobs, it also creates new opportunities, underscoring the importance of strategic implementation to mitigate adverse effects.

Addressing these multifaceted challenges requires a coordinated approach involving financial support, targeted education, clear regulations, and transparent communication. By implementing these strategies, the integration of robotic farming technologies can be made more accessible, practical, and beneficial for diverse agricultural stakeholders.

**Suggestions for Improvement**

The feedback from participants across France, the Netherlands, Spain, and Greece offers valuable insights into enhancing future demonstration events to promote the adoption of robotic farming technologies. A consistent recommendation is to increase hands-on, interactive experiences, allowing attendees to directly engage with robotic systems in real-world settings. This approach can demystify the technology and build user confidence, addressing concerns about complexity and usability.

In France and the Netherlands, where mechanical weeding and seeding technologies were showcased, participants expressed a desire for demonstrations that encompass a broader range of agricultural tasks. Expanding the scope to include activities such as soil preparation, crop monitoring, and harvesting could provide a more comprehensive understanding of the systems' versatility and practical benefits. This aligns with findings by Beaman et al. (2018), who suggest that targeted demonstrations can enhance technology diffusion among farmers.

Participants in Spain and Greece, who were introduced to autonomous spraying systems, emphasized the need for detailed training sessions and accessible educational materials. Providing printed guides, online tutorials, and technical support can facilitate continuous learning and assist farmers in integrating these technologies into their operations. This is particularly important for older farmers or those less familiar with digital tools. Research by Devitt (2021) highlights that addressing cognitive factors through comprehensive training can significantly influence the adoption of autonomous agricultural technologies.

Across all regions, there was a strong call for direct interaction with experts during demonstrations. Engaging with field specialists allows participants to address specific concerns, receive tailored guidance, and gain insights into best practices. Such interactions can build trust and credibility, which are crucial for technology adoption. A study by McGrath et al. (2023) underscores the importance of farmer engagement in the design and implementation of agricultural technologies to increase trust and adoption rates.

Additionally, participants recommended organizing live demonstrations under real-world conditions to showcase the technologies' functionality across various scenarios. Field-based demonstrations can effectively illustrate the practical benefits and adaptability of robotic systems, making them more relatable to farmers' daily experiences. This approach is supported by findings from Beaman et al. (2018), who advocate for practical exposure to new technologies to enhance adoption

Regular updates on advancements in robotic technologies were also suggested to maintain engagement and encourage continuous learning. Organising periodic seminars, workshops, and updated demonstrations can keep stakeholders informed about the latest developments, fostering a culture of innovation and openness to new tools. This is in line with the recommendations by McGrath et al. (2023) and Yeo & Keske (2024) , who emphasise the role of ongoing communication in building trust and facilitating technology adoption

In summary, the suggestions for improvement focus on enhancing interactivity, expanding the scope of demonstrations, providing comprehensive educational resources, facilitating expert engagement, and ensuring regular communication about technological advancements. Implementing these strategies can address the diverse needs of stakeholders and promote the broader adoption of robotic farming technologies.

### 4.2. FC & DT SUDs to Students

**Familiarity and Understanding of Technologies**

The survey results highlight a substantial knowledge gap among agricultural students regarding digital farming tools such as the FC and DT, with 70.4% of participants rating their familiarity as 1 out of 5. This finding underscores the urgent need for academic institutions to integrate emerging agricultural technologies into their curricula to better prepare students for the demands of modern farming practices. The lack of familiarity reflects the limited exposure that many students have to digital tools, indicating an opportunity for universities and educational bodies to address this gap.

Hands-on experiences have proven effective in enhancing students' understanding and readiness to adopt such technologies. For instance, Xu et al. (2023) emphasise that incorporating educational technologies in agricultural programmes significantly improves learning outcomes by fostering interactivity and engagement, allowing students to see the practical relevance of their studies. Similarly, a systematic review by Manning et al. (2022) highlights the critical role of early exposure to agricultural technologies during academic training, suggesting that such exposure strongly influences the likelihood of future adoption. These studies affirm the value of integrating digital farming tools into formal education settings.

To address this knowledge gap, it is essential for universities to adopt a multi-faceted approach. First, the inclusion of digital farming tools in existing courses can provide students with foundational knowledge and theoretical insights into their applications. Embedding topics such as precision agriculture, automation, and data-driven farming practices into standard curricula can help create a baseline understanding for all students. Second, providing practical, hands-on workshops where students can directly interact with tools like DT and FC allows them to gain real-world experience. Experiential learning not only bridges the gap between theory and practice but also boosts students' confidence in using such technologies. Xu et al. (2023) argue that direct interaction with these tools enhances cognitive retention and promotes problem-solving skills, making such experiences invaluable.

Additionally, collaborative projects involving industry stakeholders can play a vital role in reinforcing learning. Partnerships with agricultural technology companies can provide students with insights into real-world challenges and applications, helping them understand the broader context and implications of using digital tools. Such collaborations can also foster networking opportunities, which are crucial for career development in the agricultural sector.

Despite the positive impact of demonstrations in sparking curiosity and initiating understanding, the survey findings also suggest the need for supplementary materials to reinforce learning. Providing resources such as online tutorials, technical guides, and case studies can cater to diverse knowledge levels and support continued engagement with the subject matter. Tailoring these materials to address the varying familiarity of students can ensure that learning is accessible and effective for all participants, regardless of their starting point.

Addressing the knowledge gap in digital farming technologies among agricultural students requires a strategic and comprehensive approach. Universities need to strive to create an environment where students are not only introduced to these tools but also given ample opportunities to explore their applications and benefits. By doing so, academic institutions can prepare the next generation of agricultural professionals to harness the potential of digital farming technologies, contributing to a more innovative and sustainable agricultural future.

**Demonstration Impact and Perception**

The demonstration sessions significantly enhanced students' comprehension of the integration between FC & DT, with 94.4% reporting an improved understanding. This outcome underscores the efficacy of interactive, hands-on learning experiences in agricultural education. Such methods have been shown to deepen students' grasp of complex technological concepts, as they actively engage with the material. For instance, Greig et al. (2024) introduced the VRFARM framework, which integrates Virtual Reality into agricultural education to enhance literacy and engagement, highlighting the benefits of immersive learning environments.

Furthermore, 81.4% of participants acknowledged the potential significance of these technologies in the future of agriculture. This positive perception aligns with the growing recognition of digital tools' role in modern farming. Peladarinos et al. (2023) discuss how DTs serve as virtual counterparts, replicating the characteristics and functionalities of tangible objects, thereby facilitating comprehensive virtual replicas of farms that encompass vital aspects such as crop cultivation and soil composition.

However, the 1.9% of students who felt more confused post-demonstration, along with the 3.7% who viewed the technology less favourably, indicate areas needing attention. These findings suggest that while the majority benefit from interactive demonstrations, a minority may require additional support to fully grasp the concepts. A study by Daluba (2013) found that students taught agricultural science using demonstration methods achieved higher mean scores compared to those taught with conventional lecture methods, emphasizing the need for clear and effective demonstration techniques

To address these concerns, future demonstrations should aim to simplify complex concepts and provide relatable examples. Overall, the positive impact of the demonstrations reflects the effectiveness of interactive learning in agricultural education. By refining these methods and incorporating advanced educational technologies, educators can further enhance student comprehension and perception, preparing them for the evolving landscape of modern agriculture.

**Interactive Experience and Further Interest**

The survey results indicate that 75.9% of students believe that incorporating more interactive elements, such as setting up tasks or missions, would significantly enhance their engagement and educational experience during demonstrations. This finding underscores the importance of experiential learning in agricultural education. Experiential teaching methodologies, which emphasise learning through direct experience, have been shown to increase student engagement and deepen understanding of complex agricultural systems. For instance, integrating technologies like virtual reality and augmented reality can offer immersive experiences, allowing students to virtually explore farming scenarios, thereby bridging the gap between theoretical knowledge and practical application.

Additionally, 44.5% of students expressed a strong interest in more in-depth courses or training materials focusing on these technologies and their practical applications. This enthusiasm reflects a readiness among students to delve deeper into agricultural technologies, aligning with the growing recognition of digital tools' role in modern farming. The development of immersive virtual farm simulations has been found effective in engaging students and enhancing their learning experiences, providing a platform for them to interact with various farming operations in a controlled, risk-free environment (Nguyen et al., 2024).

However, the 18.5% of students who were neutral about the benefits of increased interactivity, and the 14.9% who expressed little to no interest in additional training, suggest that a one-size-fits-all approach may not be effective. To address this, educators might consider adopting a flipped classroom model, where traditional lecture content is delivered outside of class (e.g., through online modules), and in-class time is dedicated to interactive, hands-on activities. This approach has been shown to increase student engagement and achievement in agricultural education settings (Conner et al., 2014).

Enhancing interactivity in demonstrations and providing opportunities for deeper engagement with agricultural technologies can significantly improve student interest and learning outcomes. By adopting experiential teaching methods and leveraging immersive technologies, educators can create more engaging and effective learning environments that cater to diverse student preferences and better prepare them for the evolving field of agriculture.

**Enthusiasm and User-Friendliness**

The survey results indicate that while the majority of students perceive the FC and DT technologies as user-friendly, 40.4% expressed moderate to no enthusiasm about incorporating them into their future careers. This disparity suggests that user-friendliness alone may not suffice to foster enthusiasm among students; a deeper understanding of the practical benefits and real-world applications of these technologies is essential.

Studies have demonstrated that user-friendly interfaces in agricultural technologies significantly enhance adoption and efficiency by improving usability and accessibility. The integration of Human-Computer Interaction (HCI) principles in agricultural user interfaces has been shown to enhance efficiency and user experience, with research identifying current trends, challenges, and gaps in HCI for agricultural tools, emphasising the importance of user-centred design tailored to farmers' specific needs and skills (Ibrahim & Danmaigoro, 2024). Similarly, the development of automated, user-friendly, and affordable IoT-driven smart greenhouse systems has addressed key challenges such as energy efficiency, cost-effectiveness, and intuitive interface design, further improving usability and adoption rates (Toke et al., 2023). These examples underscore that prioritising intuitive design in agricultural technology development fosters greater adoption and efficiency.

However, enthusiasm for adopting new technologies in agriculture is influenced by several factors beyond user-friendliness. A study on the acceptance and self-efficacy of mobile technology among agricultural education students found that while ease of use is important, perceived usefulness and the ability to see tangible benefits in real-world applications play a more significant role in technology adoption (Irby & Strong, 2013).

To bridge the enthusiasm gap, it is crucial to effectively communicate the tangible benefits and real-world applicability of these technologies. Incorporating success stories and case studies into the curriculum can provide students with concrete examples of how these technologies enhance agricultural practices. Additionally, hands-on demonstrations and interactive experiences can help students appreciate the practical advantages and foster a more positive attitude towards adoption.

Ensuring that these technologies remain intuitive and accessible is also vital. Continuous feedback from users should be incorporated into the design process to address any usability issues and to adapt the technology to meet the evolving needs of the agricultural sector. By focusing on both the user-friendliness and the demonstrable benefits of FC and DT, educators and developers can work together to inspire greater enthusiasm and confidence among students, promoting widespread adoption in future agricultural careers.

**Benefits, Challenges, and Enhancements**

The feedback from students highlights several perceived benefits of integrating FC with DT, notably cost efficiency, labour savings, and reduced chemical usage. These advantages align with the broader objectives of enhancing productivity and promoting sustainable agricultural practices. For instance, the adoption of digital technologies in agriculture has been shown to improve resource management and reduce input costs, contributing to more sustainable farming systems (Geng et al., 2024; Papadopoulos et al., 2024).

However, students also identified significant challenges to the widespread adoption of these technologies. Foremost among these is the knowledge and skill gap among farmers, which could hinder effective utilisation of digital tools. This concern is echoed in the literature, where the digital divide in agriculture is recognised as a barrier that can exacerbate existing inequalities, particularly between those who can and cannot effectively use digital technologies (Kerras et al., 2022).

To address these challenges, students suggested the development of user-friendly interfaces and the organisation of seminars and training programmes to equip farmers with the necessary skills. Such educational initiatives are crucial, as they can enhance digital competencies and promote motivation for further education among students, thereby facilitating the integration of digital technologies in agriculture (Vasyukova et al., 2022).

Additionally, the high initial investment required for these technologies was a significant concern among students. Financial assistance programmes and subsidies were identified as critical to supporting farmers in adopting these innovations. This perspective is supported by studies indicating that the upfront costs associated with technology adoption may act as a barrier to entry for some farmers, preventing them from accessing the benefits of modern agricultural practices. For instance, a study on the adoption of climate-smart irrigation technologies in South Africa found that high initial investment costs hindered smallholder farmers from embracing these innovations (Serote et al., 2023). Similarly, research on the adoption of Internet of Things-based technologies in the Midwestern United States highlighted that substantial initial capital requirements deterred farmers from implementing these advanced systems

(Hundal et al., 2023). These findings underscore the necessity of financial support mechanisms to facilitate the uptake of agricultural technologies.

Concerns about the reliability of new equipment, particularly regarding potential errors and credibility, were also noted. To build trust and showcase the long-term benefits of these technologies, students recommended regular workshops, practical demonstrations, and access to educational materials. Such approaches can help in addressing scepticism and inspire greater enthusiasm among potential users.

Overall, while the integration of FC with DT offers substantial benefits, addressing the identified challenges through targeted educational initiatives, financial support, and transparent communication about the technologies' reliability and long-term advantages is essential. By incorporating these insights, future demonstrations can maximise their impact and foster greater acceptance of digital agricultural technologies among students and the broader farming community.

## 5. Conclusion

This study provides valuable insights into stakeholder perspectives on agricultural robotic solutions, reflecting the diversity of experiences and expectations among farmers, agribusiness representatives, advisors, and agricultural students. By examining both real-world demonstrations and educational settings, we have uncovered critical trends, challenges, and opportunities that can guide the future development and adoption of these transformative technologies.

The SUDs conducted in France, Greece, Spain, and the Netherlands drew a diverse group of stakeholders, predominantly farmers (ranging from 65% to 90% across regions), who brought practical, hands-on expertise to the discussion. The feedback was largely positive, with over 80% of participants rating the demonstrations as either "very good" or "excellent". Stakeholders highlighted the substantial benefits of robotic technologies, including a reduction in labour requirements, cost efficiency, and enhanced productivity. Specific advantages, such as the ability to automate time-intensive tasks like weeding, spraying, and seeding, resonated strongly. For instance, 80% of participants in France reported a positive shift in their perception of robotic farming's potential, particularly its capacity to improve operational efficiency and sustainability through precision applications and resource optimisation.

However, significant challenges emerged. High initial costs were consistently noted as a primary barrier, reflecting concerns among small and medium-sized farms about affordability. Technical knowledge gaps, particularly among older farmers, also posed a hurdle, with participants calling for targeted training programmes to build confidence and expertise. Additionally, cultural resistance to change and scepticism about technology reliability were observed, with 40% of participants in the Netherlands expressing doubts about the long-term benefits of robotic farming. Stakeholders proposed actionable solutions to address these challenges. Subsidised programmes, cooperative farming models, and user-friendly interfaces were frequently mentioned as practical strategies. Many participants emphasised the need for more interactive demonstrations, with hands-on engagement and real-world scenarios to better showcase the capabilities of these technologies. Educational seminars and clear, accessible communication about the long-term cost savings and environmental benefits were also identified as critical to fostering trust and adoption.

The feedback from agricultural students, who participated in SUDs at the AUA, highlighted both the potential and the challenges of integrating robotic technologies into agricultural education. Notably, 70.4% of students admitted to having minimal familiarity with digital tools such as Farming Controllers and Digital Twins prior to the demonstrations. Despite this initial knowledge gap, the demonstrations proved highly effective, with 94.4% of participants reporting an improved understanding of how these technologies function. The practical benefits of cost efficiency, labour savings, and reduced chemical use stood out, aligning closely with students' aspirations for more sustainable and innovative farming practices. Furthermore, 81.4% expressed optimism about the role these technologies could play in shaping the future of agriculture. Nevertheless, barriers to adoption were identified. High initial investment costs and concerns about the complexity and reliability of these systems were frequently mentioned. Students also underscored the importance of hands-on, immersive learning experiences, with 75.9% advocating for more interactive demonstrations and 44.5% expressing a strong interest in detailed training courses or materials to deepen their understanding.

The findings of this study offer valuable lessons for academia, aggrotech developers, policymakers, and farmers, all of whom play pivotal roles in shaping the future of agriculture. For academic institutions, integrating digital farming tools into curricula, alongside practical, hands-on experiences and collaborations with industry partners, can better equip students to meet the demands of modern agriculture. Aggrotech developers are encouraged to design intuitive, affordable, and adaptable technologies that address diverse farming needs, engaging stakeholders early to align solutions with real-world challenges. Policymakers and industry leaders can facilitate adoption by implementing financial incentives, clear regulatory frameworks, and accessible training programmes, empowering small and medium-sized farms to embrace these innovations. For farmers and advisors, the impact of real-world demonstrations is invaluable; hands-on engagement, supported by success stories and data-driven insights, builds confidence and highlights the transformative potential of robotic farming technologies. By addressing these challenges collectively and leveraging stakeholder insights, the agricultural sector can unlock the full potential of robotic solutions, advancing efficiency, sustainability, and resilience. Achieving this vision will require a collaborative effort, where the perspectives of farmers, students, researchers, and policymakers are harmonised to drive innovation and adoption forward.

## 6. CRediT authorship contribution statement

**George Papadopoulos:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualisation; **Maria-Zoi Papantonatou:** Writing – original draft, Resources, Investigation, Formal analysis; **Havva Uyar:** Writing – original draft, Methodology, Investigation, Formal analysis; **Konstantinos Nychas:** Writing – original draft, Resources, Investigation, Formal analysis, Methodology; **Vasilis Psiroukis**: Writing – review & editing, Validation, Resources, Methodology; **Aikaterini Kasimati:** Writing – review & editing, Methodology; **Ard Nieuwenhuizen**: Writing – review & editing; **Frits Van Evert**: Writing – review & editing, Methodology, Supervision; **Spyros Fountas:** Writing – review & editing, Supervision.

## 7. Declaration of competing interest

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.

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## 9. Ethics Statement

Not applicable.

## 10. Data availability

Data will be made available upon request.

## 11. Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT, an AI language model by OpenAI, to improve the language of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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