Optimising decision support tools for the agricultural sector

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Optimising decision support tools for the agricultural sector

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Abstract

Several challenges threaten the viability of agriculture in the Mediterranean region, for instance, climate change and variability, land degradation and desertification, environmental and social pressures in rural areas, and the arrangement and extent of properties. These challenges require the attention of farm managers and effective decision-making that can safeguard the natural resource base, enhance resilience and food security, and promote sustainable production landscapes. Decision Support Tools (DSTs) offer valuable assistance in addressing these challenges by improving the decision-making process for both farmers and advisors. They enable data-informed decisions that can enhance the sustainability performance of agricultural businesses in the region. A crucial component of designing a proficient DST is the prompt involvement of stakeholders using a participatory approach to define the needs and requirements of end users. In this study, we engaged twenty-nine stakeholders, including farmers, advisors, extension officers, policy makers, and industry representatives from the Argolida regional unit and the Greek National Ministry of Rural Development and Food. This engagement was aimed at conducting a comprehensive analysis of user needs. To achieve this, we employed the Q-methodology approach to gain a thorough comprehension of the viewpoints and requirements of these diverse stakeholder groups. The results illustrated factors such as the need for user-friendly interfaces, the importance of data accuracy and reliability, the benefit of flexibility and adaptability, and the need for appropriate training and support. These findings can aid the effective development of DSTs so that emerging challenges can be framed in a manner that will facilitate solutions.

Keywords Decision support tools · Decision-making · Q-methodology · Participatory approach · Sustainability · Mediterranean agriculture

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1 Introduction

Farm businesses in the Mediterranean basin are encountering significant obstacles, which can be attributed to both inherent factors such as small land holdings, an aging rural population, and limited education levels, as well as external factors like climate change, land degradation, and the scarcity of natural resources. These challenges collectively impact the prospects for sustainable agriculture in the region (Iakovidis et al., 2023).

Addressing sustainability challenges through DST adoption and use can be more effective when the tools are co-produced with key stakeholders as this approach may help to address the complex nature of contemporary sustainability challenges better than traditional scientific approaches (Norström et al., 2020). The traditional linear model of knowledge production, where researchers generate information and then pass it on to policy makers is being challenged by a co-production approach. This approach emphasises the meaningful interaction between researchers and knowledge users, such as policy makers, to collaboratively create knowledge that is relevant and actionable in decision-making processes (Mach et al., 2020).

However, before engaging in the co-production approach it is crucial to identify the needs and requirements of the end-users (Kharade & Peese, 2012). This involves actively involving the stakeholders in the research process and understanding their perspectives, priorities, and knowledge gaps (Smith et al., 2022). Such a participatory approach allows researchers and developers to gain insights into the practical problems and concerns faced by decision-makers, enabling them to ensure that research is aligned with the needs of the intended users and address real-world challenges more effectively.

Hence, by involving various stakeholders, we aim to delve into their understanding of DSTs and more precisely identify their needs. This process facilitates the recognition of DST requirements, allowing us to frame emerging challenges in a way that paves the path for future collaborative service development for DSTs. In this study, we delve into the needs and demands of both farmers and advisors, with the ultimate goal of bolstering the adoption and utilisation of DSTs.

Leveraging efficient DSTs in the field of agriculture presents a promising pathway to augment the overall sustainability performance of farms (Lundström et al., 2016). This, in turn, allows for the more effective addressing of broader regional challenges. Innovative and technologically sophisticated DST solutions offer farmers and advisors a mechanism to optimise their production procedures, leading to enhanced economic, ecological, and social results (Lundström et al., 2016). Despite variations in their approaches, these tools share a common objective: to improve the effectiveness of farm management by seamlessly integrating scientific insights into practical use, with a user-friendly approach that supports food production and ultimately livelihoods (Hochman & Carberry, 2011; Rossi et al., 2014).

A DST supports management practices by enabling informed and evidence-based decision-making that takes into consideration all relevant and available data and information (Dicks et al., 2014). These decisions could be strategic, tactical, or operational and can have an immediate impact on the sustainability performance of the farm business (Lundström, 2016).

Despite the advantages indicated, numerous studies (for instance (Alvarez & Nuthall, 2006) and (Rose et al., 2016)), spanning almost three decades, have concluded that the uptake of DSTs remains regrettably low for a multitude of reasons. These reasons include the cost–benefit ratio; tool complexity; unsuccessfulness to address the actual problem;

lack of integration with existing systems and poor computer literacy of users. As Stewart et al. (2013), and Michels et al. (2020) concluded, the challenges of adoption are diverse, and successful DST uptake depends on satisfying a range of criteria rather than just addressing one.

Therefore, the objective here is to address the above challenges and the gap in the literature on DST development. Firstly, our study introduces a novel and holistic approach to user need analysis, considering a diverse group of stakeholders in the context of Mediterranean-based farming systems. This approach ensures a comprehensive understanding of varying needs. Secondly, we contribute to the literature on DSTs by developing a methodology specifically tailored to the social and political demographics of Mediterranean farming systems. This methodology serves as a valuable addition to tools available for decision-makers addressing the complex challenges faced by agriculture in the region. Thirdly, our research provides a detailed framework for user need analysis, facilitating the effective prioritization of needs among different stakeholder groups. This framework not only identifies diverse needs but also ranks them, offering a nuanced understanding for informing strategic interventions and policy decisions. Lastly, our study illustrates a method easily adopted by stakeholders in the agricultural sector, especially policymakers, aiding in the development of solutions to address sustainability challenges in Mediterranean-based farming systems.

The following sections outline the methodology employed before presenting results and concluding comments with key messages.

2 Materials and methods

2.1 Outline of research

This research employs a participatory methodology to involve stakeholders in identifying the needs and prerequisites for the effective utilisation and acceptance of Decision Support Tools (DSTs), with the ultimate goal of enhancing the sustainability of farming. Within this framework, the subjective perspectives of stakeholders regarding DSTs are explored through a case study conducted in the Argolida region of the Peloponnese, Greece.

To exemplify the collaborative efforts of stakeholders dedicated to the sustainable future of agriculture, we assembled groups comprising farmers, advisors, extension officers, industry representatives, and policy makers to engage in focused group discussions. Engaging a diverse range of stakeholders, including farmers, advisors, extension officers, industry representatives, and policymakers, in the development of decision support tools for agriculture is crucial for a comprehensive and effective approach (Rose et al., 2016). Farmers' firsthand experiences provide practical insights, while advisors and extension officers bridge the gap between research and application, ensuring the tools are relevant in real-world farming scenarios. Industry representatives contribute expertise in the latest technologies and market trends, aligning tools with current industry practices. Collaboration with policymakers ensures that the tools align with overarching agricultural policies, fostering regulatory compliance and sustainability. This inclusive approach not only increases the likelihood of user adoption but also facilitates a smoother implementation process, leveraging diverse perspectives for innovative, interdisciplinary solutions (Terrado et al., 2023). Ultimately, engaging stakeholders in the development process enhances the tools' relevance, effectiveness, and sustainability, contributing to a more resilient and sustainable future for agriculture (Lu et al., 2022). Subsequently, a Q-methodology approach was employed to serve as a foundation for identifying the specific requirements and needs of farmers and advisors about the use and adoption of DSTs. This method encompassed a blend of qualitative and quantitative techniques, allowing for a thorough examination of the stakeholders' subjective viewpoints and beliefs.

2.2 Q-methodology

Q-methodology is a research and data analysis technique used in the social sciences to study subjectivity and explore individuals' viewpoints and perspectives on a particular topic or issue (Valenta & Wigger, 1997). An interesting feature of the Q methodology is that the research is better applied to small samples (Brown, 2003). The Q methodology objective –the eliciting of a diversity of opinions—can be achieved with small samples as long as the sharing of diverse opinions is encouraged by the researcher (Gabor & Cristache, 2021). Sampling when using the Q methodology differs from many social science norms in that selecting the participants (P-set) for the study does not follow the criterion of random choice but allows for the selection of participants based on the chance to bring more subjectivity and new viewpoints and beliefs to the research.

In this research, the different stages of the methodology application were the following:

- Stage 1: Developing the Q-Set
  - Literature review for the extraction of the statements.
  - 40 statements were finally, aimlessly selected by the analysis software.
- Stage 2: Finalising the P-Set
  - Selection of stakeholders for the sample.
  - 29 farmers, advisers, extension officers, industry representatives, and policy makers were selected purposely.
- Stage 3: Q-sorting
  - Focus group organisation for participants.
  - Participants rank the Q-Set in a forced distribution grid (− 5 to + 5).
- Stage 4: Principal component analysis—Q-factor analysis
  - PCA was performed using "R" software, package "qmethod" 1.8.
- Stage 5: Understanding the factors
  - Developing factor arrays that essentially provide an extensive depiction of the main perspectives and beliefs, being indicated by the P-Set.

2.2.1 Stage 1: Developing the Q-set

Developing the Q-set has to do with the formulation of statements relevant to the subject of investigation. In analogous studies, this process is known as *"concourse sampling"* where key statements are chosen from pertinent academic literature or drawn from an extensive pool of potential expressions pertaining to the subject at hand (Zabala & Pascual, 2016). These selected statements should encompass the knowledge and concepts that can reasonably be articulated regarding the topic, whether found in scholarly literature or other publicly accessible resources. While achieving a comprehensive grasp of the entire concourse is undoubtedly challenging, the compilation of items, often in the form of written statements, should offer a practical approximation of its breadth (Farrimond et al., 2010). Consequently, the relative comprehensiveness of a well-constructed concourse poses a limitation for every Q-methodology study, as does the representativeness of the sample drawn from it (Kampen & Tamás, 2014).

For this project, a systematic literature review of peer-reviewed articles was conducted by employing keywords associated with the research topic and utilising Boolean operators (AND, OR, and NOT). This search was carried out in two major multidisciplinary databases of bibliographic information, namely Scopus and Web of Science, with no restriction on the timeframe of publication. The sole criterion for inclusion was the number of citations received by each article.

The search string used was formed as follows:

- ‘‘decision support tools’’ OR ‘‘decision support systems’’ AND ‘‘decision-making’’ OR ‘‘farm sustainability’’ OR ‘‘farm management’’ OR ‘‘effective design’’ AND ‘‘agriculture’’

To reach the highest possible explanatory power, the statements included in this step should represent a variety of different opinions (Brown, 1993). To present the findings of the comprehensive examination of the literature, a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement was used (Page et al., 2021). The process followed is shown in Fig. 1:

From the review step, 23 articles were selected. After a thorough review of these 23 articles, 87 statements were extracted from the original texts by the researchers (Online Appendix 1—Concourse). These statements were imported into the “R” software for analysis using the function “import.q.concourse” of the package “qmethod” 1.8 (Zabala & Held, 2020) and with the function “build.q.set”, 40 were used to randomly,[1] select the Q-set.

The selected set of statements typically between 40 and 80 (Watts & Stenner, 2012a, 2012b) are normally written on one card each, and in later steps, these cards are given to participants to rank them over a grid that represents a prearranged frequency distribution (Zabala & Pascual, 2016). The number of statements being used in a Q-methodology varies with subject. Ultimately, a sufficient number of statements that cover the viewpoints on the topic is needed whilst noting that an excessive number of unnecessary statements may reduce the motivation of the participants to maintain engagement throughout the entire ranking process and respond effectively to the research question (Watts, 2013).

2.2.2 Stage 2: Finalising the P-set

This stage entails the identification of individuals who will constitute the Q participants, often referred to as the “P-set.” Q-methodology primarily employs purposive sampling for participant selection. In this approach, individuals are chosen based on their capacity to express a distinct perspective on the subject of inquiry, as well as their possession

[1] The function “build.q.set” carries out various tests to ascertain the accuracy and coherence of inputs (for example, statements must be presented as a matrix) and segments a collection of items into a subset of chosen items. It produces a dataframe where the row names correspond to the handles, and the columns represent the languages, if relevant (Zabala & Held, 2020).

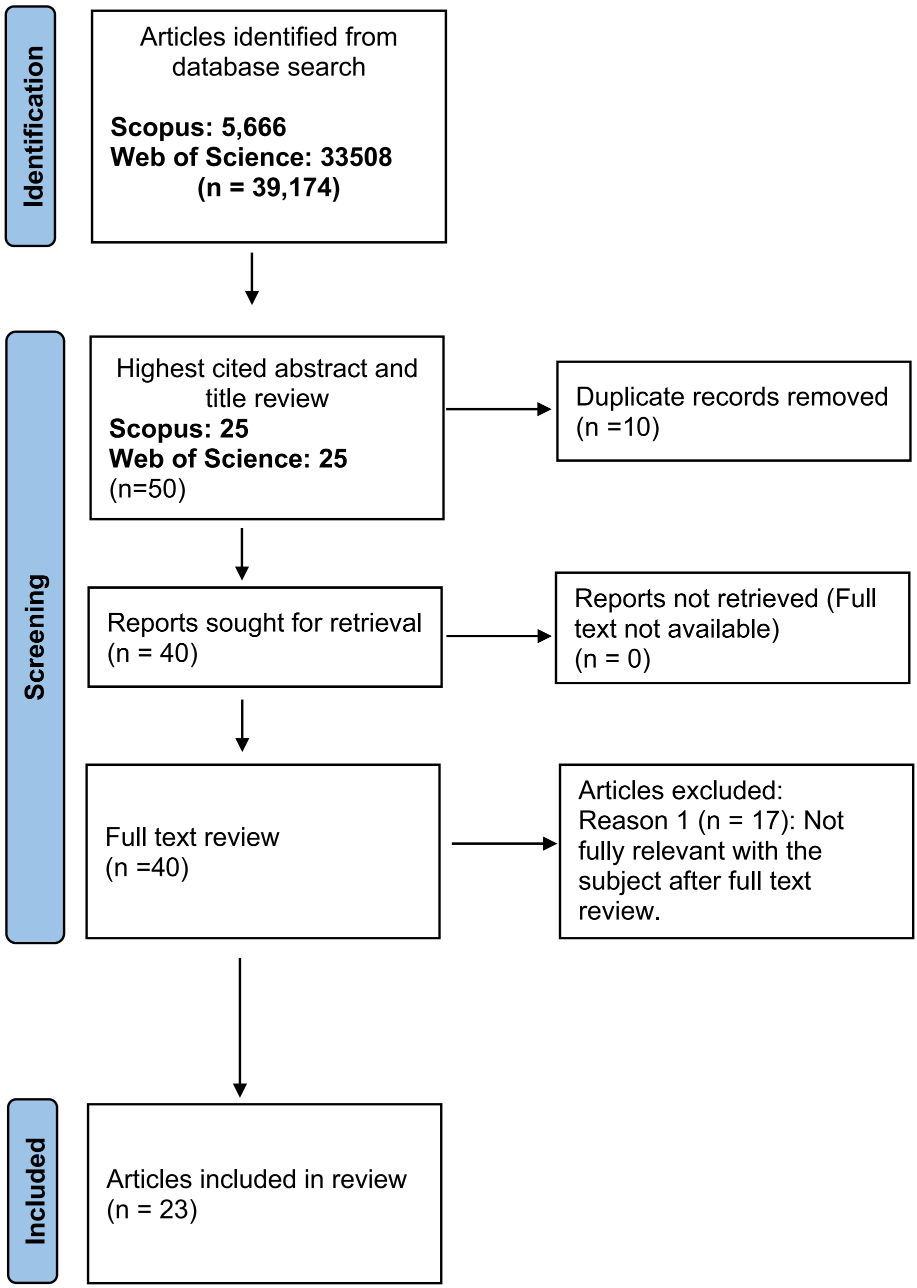

Fig. 1 Flow chart of ''Decision support tools'' systematic review. Adapted from Page et al. (2021)

of relevant knowledge, expertise, and professional experience—their viewpoints hold significance. Furthermore, it is crucial to assemble a P-set that can effectively mirror the diverse subjective viewpoints relevant to the subject under investigation. Lastly, participant selection should be carefully orchestrated to ensure that the researcher can comprehensively explore all the perspectives associated with the subject of study.

The P-set represents the variables and not the sample (statements), so it does not require a large number of participants, usually not more than 40 (Brown, 2003). More recently (Webler et al., 2009) commented that the typical number of participants sufficient for a given P-set is between 12 and 36.

In this research, the 29 stakeholders were engaged as the P-set, and their professions and coding are presented below:

- 10 farmers, with code names Far1—Far10,
- 5 advisers, with code names AD1—AD5,
- 5 extension officers, with code names EO1—EO5,
- 5 industry representatives, with code names IR1—IR5, and
- 4 policy makers, with code names PM1—PM4.

The selection of the stakeholders was made from the geographical region that falls within the scope of the research, the regional unit of Argolida, Peloponnese, Greece except for the policy makers who were recruited from the National Ministry of Rural Development and Food of the country.

2.2.3 Stage 3: Q-sorting

Data collection occurred during October and November 2022. In this process, the 40 statement cards, as outlined in step 1, were utilised for the Q-sorts, employing a scale ranging from (−5) to (+5), as illustrated in the subsequent figure. Participants were instructed to assign a (+5) to statements most aligned with their viewpoints and a (−5) to those least in accordance with their perspectives, with "I" representing the individual participant.

The Q-sorting was performed within focus groups, each consisting of 5 individuals. Among these groups, two were composed of farmers, one consisted of advisers, and another comprised extension officers. However, due to the constraints of industry representatives and policy makers, including their other commitments and geographic locations, in-person focus groups were not feasible. Therefore, these individuals were provided with detailed instructions and guidance, along with the necessary Q-sorts (see Fig. 2) and the Q-set, which they completed individually.

The focus group sessions occurred between the 24th and 28th of October 2022, with each session lasting approximately 1 h and 45 min on average. Completion of the Q-sorts by the industry representatives and policy makers was accomplished by the 14th of November 2022.

2.2.4 Stage 4: Principal Component Analysis—Q-factor analysis

Stage 4 within the Q-methodology framework involves Q-factor analysis, which employs a multi-step approach. Initially, it utilizes a Principal Component Analysis (PCA) to extract factors. Subsequently, a separate factor analysis is performed to elucidate the relationships between these factors. A varimax rotation is then applied to enhance the clarity of these relationships and maximise the variance in the primary factors. Automatic flagging is used to calculate the statement scores, and the Pearson correlation coefficient is applied for further analysis.

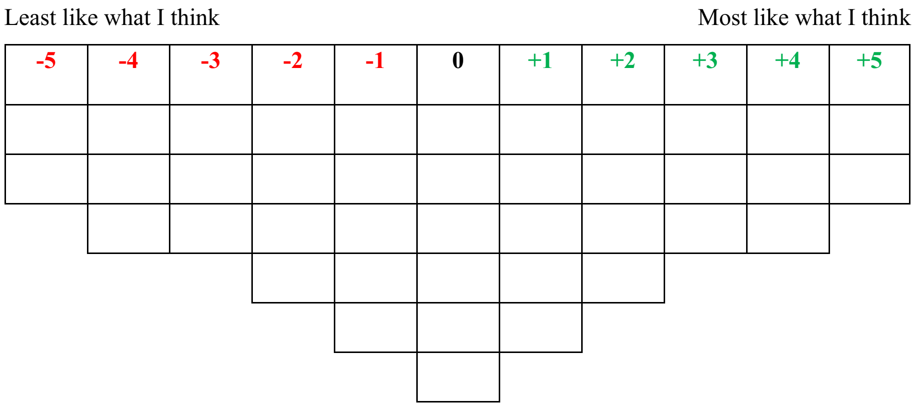

Fig. 2 Exemplar blank Q-sort grid

The determination of the number of factors derived from the Q-factor analysis is made using the Kaiser-Guttman criterion. Additionally, the Scree test, which entails constructing a screeplot, is employed to make informed decisions regarding the retention of principal components. These two methods collectively provide a clear assessment of the strength and potential explanatory capacity of the identified factors.

The analysis of the Q-sorts was conducted using the package "qmethod" 1.8 (Zabala & Held, 2020) of R software, version 2022.07.2 that implemented a number of tests on the validity and consistency of inputs.

2.2.5 Stage 5: Understanding the factors

Understanding and interpreting the factors was accomplished by creating factor arrays, which entail generating representative Q-sorts for each of the factors identified. These factor arrays were derived from the weighted average Q-sorts of participants who exhibited a strong association with each respective factor. The arrangement of statements within a factor Q-sort holds significance, as it ensures the provision of a comprehensive overview of the predominant perspectives and views expressed by the participants in the P-set.

To validate the accuracy and effectiveness of the qualitative interpretation, several approaches can be employed. Firstly, it can be cross-referenced with additional data from participants whose perspectives significantly contributed to a particular factor. Furthermore, simply seeking feedback from the participants themselves can serve as a means of verification. These "loaded" opinions, originating from participants who exerted substantial influence on a specific factor, play a crucial role in confirming the precision and efficacy of the data interpretation.

3 Results

This section is structured to provide a clear and coherent presentation of the results, facilitating the interpretation and discussion of their implications in subsequent sections of this paper. Through rigorous data collection, quantitative analysis, and qualitative examination,

Table 1 The sociodemographic structure of the P-set

Characteristics		P-sample					%
		Farmers (#10)	Advisers (#5)	Extension officers (#5)	Industry representa-tives (#5)	Policy mak-ers (#4)	
Gender	Male	8(80%)	5 (100%)	3 (67%)	5 (100%)	2(50%)	79
	Female	2 (20%)	0	2 (33%)	0	2(50%)	21
Age group	18–39 years	0 (0%)	0	0	0	0	0
	40–59 years	7 (70%)	5 (100%)	5 (100%)	5 (100%)	4 (100%)	94
	60–74 years	3 (30%)	0	0	0	0	6
Education	Primary	1 (10%)	0	0	0	0	3
	Secondary	4 (40%)	0	0	3 (67%)	0	25
	Post-second-ary	1 (10%)	0	0	0	0	3
	University	4 (40%)	5 (100%)	5 (100%)	2 (33%)	4 (100%)	69

Table 2 Factor characteristics

	F1	F2	F3	F4	F5
Average reliability coefficient	0.8	0.8	0.8	0.8	0.8
Number of loading Q-sorts	9	6	4	4	2
Eigenvalues	4.4	3.7	2.9	2.8	2.2
Explained variance (%)	15	12.9	10	9.5	7.8
Cumulative explained variance (%)	15	27.9	37.9	47.4	55.2
Composite reliability	0.97	0.96	0.94	0.94	0.89
Standard error of factor scores	0.16	0.2	0.24	0.24	0.33

we have unearthed valuable insights that contribute to our understanding of the viewpoints and beliefs of the stakeholders engaged in the research.

3.1 Sociodemographic structure and factor analysis

The structure and sociodemographic characteristics of the P-set are presented in Table 1.

Five factors were extracted for this research. These factors presented in Table 2 satisfy the Kaiser-Guttman criterion with eigenvalues (EV) over 1 and the five factors account for 55.2% of the total study variance. According to Watts and Stenner (2012a, 2012b), a percentage above 35–40% would be considered a sound outcome.

The composite reliability of each factor is above average (0.8). In Q-methodology, the emphasis is on participants' subjectivity rather than on validity and reliability. However, perfect agreement means similar results, whereas perfect reliability illustrates a high correlation (Thomas, 2017).

Table 3 serves as a visual representation of the intricate interplay between the characteristics of our study participants and their attribution to each of the identified factors. Within this table, the data collected from our research have meticulously been organised, aligning the specific participant characteristics with the corresponding factors that emerged from

Table 3 Characteristics and participants for each factor

		Factor 1 (#9)	Factor 2 (#6)	Factor 3 (#4)	Factor 4 (#4)	Factor 5 (#2)
Gender	Male	4 (45%)	5 (83%)	4 (100%)	4 (100%)	2 (100%)
	Female	5 (55%)	1 (17%)	–	–	–
Age group	18–39 years	–	–	–	–	–
	40–59 years	7 (78%)	6 (100%)	4 (100%)	4 (100%)	2 (100%)
	60–74 years	2 (22%)	–	–	–	–
Education	Primary	1 (11%)	–	–	–	–
	Secondary	2 (22%)	–	1 (25%)	2 (50%)	2 (100%)
	Post-secondary	–	–	–	–	–
	University	6 (67%)	6 (100%)	3 (75%)	2 (50%)	–
Farmers		4 (45%)	1 (17%)	1 (25%)	1 (25%)	2 (100%)
Advisers		1 (11%)	–	2 (50%)	–	–
Extension officers		2 (22%)	2 (33%)	–	1 (25%)	–
Industry representatives		1 (11%)	–	1 (25%)	2 (50%)	–
Policy makers		1 (11%)	3 (50%)	–	–	–

our analysis. By doing so, the nuanced relationships and associations that underpin our findings are aimed to be highlighted. Table 3 illustrates how the characteristics, and the participants were associated and attributed to each factor:

3.2 Understanding the factors

To enhance the interpretation of factors, two distinct sets of data were employed. Initially, socio-demographic data concerning the P-set, which includes participant characteristics, and their affiliations with specific factors, as illustrated in Table 2 and 3, were utilised. Subsequently, the results from the Q-factor analysis, as presented in Table 4, were also incorporated into the interpretation process.

Additionally, a valuable interpretive tool known as "crib sheets," as recommended by Watts and Stenner (2012a, 2012b), was employed. These crib sheets consist of statements categorized into four distinct groups. Two of these categories encompass the statements that received the highest rating in the factor array, as well as those receiving the lowest rating. The other two categories pertain to statements that were rated either higher or lower, respectively, within a particular factor compared to any of the other identified factors.

This categorisation is invaluable as it enables identifying the statements that exerted the most substantial influence and made a critical contribution within each factor array. A factor array, in this context, is a single Q-sort arranged to depict the perspective of a specific factor (Morea, 2022; Watts, 2013). These five-factor arrays were created by closely examining the statements that exhibited the strongest associations with each factor, based on the Q-sorts.

Q-factor analysis resulted in producing z-scores for both statements and factors. The z-score is a weighted average of the values that the Q-sorts give to a statement most closely related to the factor (Zabala & Pascual, 2016). In practical terms, it indicates a statement's relative position within the factor. In Table 4, the factor z-scores for the statements are

Table 4 Factor z-scores for statements and normalized and rounded scores for Q-sorts

		Factor Z-scores					Factor scores (Heat mapping)				
	STATEMENTS	**zsc_f 1**	**zsc_f 2**	**zsc_f 3**	**zsc_f 4**	**zsc_f 5**	**f1**	**f2**	**f3**	**f4**	**f5**
1	Research of DST must focus on the right application areas	1.01	0.57	0.54	-0.43	1.46	3	1	1	-1	4
2	The number of case studies must increase to improve relevance	0.45	0.34	-0.06	-1.1	0.73	2	0	0	-3	2
3	Initial cost and cost of use of DST must be efficient	1.98	0.62	0.77	0.63	0	5	1	2	2	0
4	A broader theoretical psychological foundation may cause DST research to embrace practice than ignore it.	0.4	-0.64	-1.24	-1.51	-1.46	1	-2	-4	-5	-4
5	Farmers should actively involve in the processes of agricultural technology development	2.15	-0.28	1.56	1.53	1.83	5	-1	4	4	5
6	DST do not take into account uncertainty and dynamic factors.	-1.7	-1.04	1.19	-1.09	-1.1	-5	-3	4	-3	-3
7	DST must match the skills and habits of different age groups	0.93	0.45	-0.27	-1.91	-1.83	3	1	0	-5	-5
8	DST use results in effort savings but not improved decision performance	-1.6	-1.4	-1.39	-0.62	-1.1	-5	-4	-4	-2	-3
9	Commercial agronomists should train, be supported and accredited for DST use	1.5	-1.16	0.87	0.89	0	4	-4	2	3	0
10	DST must comply and satisfy legislative and market requirements.	0.81	-0.36	0.14	0.1	1.1	2	-1	1	0	3
11	DST low adoption rate is due to low adaptation to the farm situation	-1.44	0.47	-0.76	0.29	-0.73	-4	1	-2	1	-2
12	The low practical relevance of DST is a symptom of research inertia.	-0.76	-0.19	1.06	-1.47	-1.1	-2	0	3	-4	-3
13	Managers' fluid approach to decision-making requires ongoing monitoring of the consequences of past decisions	0.11	-0.06	-0.84	-0.62	-1.46	0	0	-3	-1	-4
14	The low practical relevance of DST is due to farmers' inertia	-1.04	-0.14	-2.13	-0.99	0.37	-3	0	-5	-2	1

Table 4 (continued)

		Factor Z-scores					Factor scores (Heat mapping)				
	STATEMENTS	**zsc_f 1**	**zsc_f 2**	**zsc_f 3**	**zsc_f 4**	**zsc_f 5**	**f1**	**f2**	**f3**	**f4**	**f5**
15	DST must perform a useful function and work well	0.81	1.54	0.77	0.14	0	2	4	2	0	0
16	DST must be applicable to all scales and types of farming	0.94	0.75	-0.3	0.42	1.1	3	2	-1	1	3
17	DST users have access to information about such tools	0.33	-0.56	-0.49	0.24	0.73	1	-1	-1	1	2
18	DST low adoption rate is due to lack of confidence	-1.07	0.14	-0.4	-0.62	1.1	-3	0	-1	-1	3
19	DST should be sustainable in design as well as through design	0.16	0.68	0.77	0.2	-0.37	0	2	2	0	-1
20	DST low adoption rate is due to lack of incentive to learn and adopt new practices	-0.58	0.76	0.89	0.3	0.73	-1	2	3	1	2
21	DST assist my decision-making regarding my management approach	1.57	1.82	-0.82	0.92	-0.37	4	5	-3	3	-1
22	DST are usually used for the exception and rarely for the routine situations	-1.26	-2.23	0.09	-1.25	-1.46	-4	-5	0	-4	-4
23	DST are not used to their full potential	-0.72	0.53	1.49	-0.1	0	-2	1	4	0	0
24	DST role lies in their potential to support social learning between stakeholders	0.1	-0.92	0.06	-1.05	1.46	0	-3	0	-3	4
25	A DST must be inexpensive to acquire.	1.28	0.95	0.93	-0.16	0.73	4	3	3	-1	2
26	DST provide an honest and responsible test of underlying science	0.17	-0.73	-0.5	-0.79	1.46	0	-2	-2	-2	4
27	DST must have multiple benefits for the stakeholders involved	0.26	1.59	-0.31	0.64	1.83	1	5	-1	2	5
28	Subsidies must act as an incentive for the farmer towards sustainable farming	-0.72	0.68	1.59	0.4	-1.83	-2	2	5	1	-5
29	Farmers need to be trained deeply to learn and apply new technologies	0.25	1.33	0.56	1.75	-0.37	1	4	1	4	-1
30	Production inputs should be used under provisions and restrictions	0.88	-0.86	-1.07	-0.03	0.37	2	-3	-3	0	1

Table 4 (continued)

		Factor Z-scores					Factor scores (Heat mapping)				
	STATEMENTS	**zsc_f 1**	**zsc_f 2**	**zsc_f 3**	**zsc_f 4**	**zsc_f 5**	**f1**	**f2**	**f3**	**f4**	**f5**
31	All available information regarding my profession can be accessed easily.	-0.6	-1.83	-2.14	0.06	0.37	-1	-5	-5	0	1
32	DST assist my decision-making regarding soil properties	-0.31	-0.4	-0.71	1.77	-0.37	-1	-1	-2	5	-1
33	DST are not adapted to the trade-offs and high complexity that characterises farmers' decision-making	-1.16	-0.67	0.5	-1.35	-0.37	-3	-2	1	-4	-1
34	DST use requires good IT skills	-0.62	-0.78	-0.76	0.82	0.37	-1	-2	-2	2	1
35	Agricultural practitioners are concerned about using certain smart technologies	-0.81	-0.53	-0.13	-0.39	0.37	-2	-1	0	-1	1
36	The success of DST implementation is based on design rather than on iterative learning.	-0.53	-0.26	-0.29	0.61	-0.73	-1	0	-1	2	-2
37	DST assist my decision-making regarding crop practices	0.42	1.57	-1.48	1.15	0	1	4	-4	3	0
38	DST low adoption rate is due to tedious data input requirements	-1.39	-1.68	-0.22	-0.86	0	-4	-4	0	-2	0
39	DST is improving managerial decision-making	0.04	1.07	0.57	1.95	-0.73	0	3	1	5	-2
40	DST must be relevant to the individual farm circumstances	-0.22	0.83	1.97	1.53	-0.73	0	3	5	4	-2

presented. In colour for each factor, there is the statement that “loads heaviest on it” meaning it is highly correlated to that factor.

Table 4 presents the five factor arrays generated in this study, facilitating the interpretation and elucidation of the factors concerning the attitudes and opinions expressed by individuals associated with each factor. To illustrate, in Factor 1, Statement 5 exhibited a notably stronger association than any other statement and received the highest ranking from one industry representative and two farmers. The z-score, which indicates the degree of correlation between the statement and the factor, reflects the extent of this association. Statements that demonstrate a significant correlation with each factor are color-coded, with green indicating positive loading and red signifying negative loading.

Table 4 also presents the normalised and rounded scores from the Q-sorts for each factor and a heat map for the final scores. To improve the visualisation of the results, the heat map with the final scores was created with shades of green colour for statements “Most like what I think” and shades of red colour for statements “Least like what I think”. The darker the shades, either green or red, represent the highest or lowest correlation of the statement to the factor. The lighter the shades, the less correlated statements to the factor under consideration. The numerical scores (− 5 to + 5) were added, to help with the positive or negative correlation of the statements to the factors. Positive numbers up to + 5 revealed a strong correlation while negative numbers revealed a poor correlation of the statements to the factors. Taking into consideration all the above the interpretation and definition of the five factors are presented below:

3.2.1 Factor 1: "Cost Efficiency—Education/Training"

For Factor 1 major attention was given by the participants to the cost of attainment and use of DSTs, the active involvement of farmers in the process of agricultural technology development, and the need for farmers to be offered training to learn about and apply new technologies. The issue of low adoption due to poor adaptation of the DSTs to the farm situation (for instance due to burdensome data input requirements or lack of confidence in the technology), has been downgraded and not seen as so important.

3.2.2 Factor 2: "Functionality—Performance"

In the context of Factor, 2 respondents pinpointed the help DST offered to the management approach of end users and the multiple benefits for the stakeholders involved. In contrast, they didn't agree with the perception that DST are only used in exceptional circumstances noting their usefulness in more routine management.

3.2.3 Factor 3: "Relevance—Usefulness"

For this factor, participants acknowledged the necessity for DST to be applicable and advantageous to specific farm situations. Furthermore, they believed subsidies (or grants) must serve as an inducement for farmers to adopt more sustainable farming techniques. They refuted the notion that all relevant information pertaining to their profession was easily accessible and that farmers' reluctance to utilise DST stems from their inertia toward change.

3.2.4 Factor 4: "Applicability—Innovation Uptake"

The participants involved in this factor expressed a high level of agreement about the potential of DSTs to enhance managerial decision-making. Specifically, they noted that DSTs can be particularly useful in facilitating decision-making related to soil properties and should be applicable to farming operations of all scales. Conversely, participants held divergent views regarding the necessity for DSTs to be tailored to the skills and habits of different age groups. Furthermore, they argued that a more comprehensive theoretical foundation in psychology may serve to enhance the practical application of DST research rather than impede it.

3.2.5 Factor 5: "Active Involvement—IT skills"

The participants affiliated with the fifth factor expressed their favourable outlook toward the active participation of farmers in the development of agricultural technology. Moreover, they believed that the adoption of DSTs should have manifold advantages for all stakeholders involved. However, they emphasised that farmers need to undertake extensive training to gain proficiency in the application of new technologies. Conversely, this group of participants did not support the notion that DSTs should accommodate the skills and practices of different generations. Additionally, they did not view subsidies as an effective incentive for farmers to pursue sustainable farming practices.

In summarising the analysis, it becomes evident that the identified factors play a pivotal role in enhancing our understanding of the diverse needs and requirements of end users, thereby contributing to improved adoption and effective use of DSTs. Factor 1, "Cost Efficiency—Education/Training," underscores the importance of making DSTs economically viable while ensuring that educational and training components are accessible and tailored to end users' needs. Factor 2, "Functionality—Performance," emphasises the significance of ensuring that DSTs not only offer a range of functions but also perform optimally, meeting the practical demands and expectations of users. Factor 3, "Relevance—Usefulness," highlights the necessity of DSTs aligning with the specific challenges and objectives of the agricultural sector, ensuring their relevance and practical utility for end users. Factor 4, "Applicability—Innovation Uptake," stresses the importance of designing DSTs that are not only applicable to diverse agricultural contexts but also encourage the uptake of innovative solutions, enhancing the tools' overall effectiveness. Lastly, Factor 5, "Active Involvement—IT Skills," underscores the role of engaging end users actively and ensuring that the tools are designed with a user-friendly interface, considering varying levels of IT skills among stakeholders. By addressing these factors comprehensively, DSTs can be tailored to meet the multifaceted needs of end users, promoting their acceptance, adoption, and successful utilisation in the agricultural sector. These needs and requirements are summarised in Table 5.

4 Discussion

In this research, Q-methodology was used to analyse a set of statements from the literature related to DST adoption and use. Instead of directly involving the end-users (farmers and advisers) in defining and ranking their needs and requirements, a more informative, holistic, and innovative approach was employed. Five different categories of stakeholders, which included farmers, advisers, extension officers, policy makers, and industry representatives, were engaged. These stakeholders were chosen based on their knowledge and expertise in the field of DSTs.

Forty statements were selected from peer-reviewed articles with the highest number of citations on the topic (Subagja et al., 2022) of DSTs from the literature. These statements represented various aspects of DST adoption and use, covering a range of perspectives and issues relevant to end-users. By utilising Q-methodology and involving multiple stakeholders, the objective was to gain a deeper insight into the needs and requirements of end-users regarding DST adoption and use. The analysis of the statements allowed the identification of common themes, patterns, and differing viewpoints among the stakeholders, providing a broader and more holistic understanding of the topic.

Overall, the research has explored the perspectives of various stakeholders and gained an understanding of the needs and requirements of end-users related to DSTs. This was achieved without directly involving these stakeholders in the ranking and definition process but rather by integrating their scientific knowledge and subjective perspective into the analysis. This approach can inform the development and implementation of DSTs that align with the practical needs and preferences of the end-users while being grounded in scientific knowledge and evidence.

4.1 Methodology applications

The results show that the Q methodology is a solid tool and aligns perfectly with eliciting end users' subjective thoughts about DST use and adoption. This is similar to the findings of Carr and Liu (2016) and Cuppen et al., (2016).

As noted by Pereira et al. (2016) the use of Q-methodology enabled a shift in focus from the technology itself to the potential users' needs and their attitudes and beliefs towards it. This approach enabled stakeholders to express their viewpoints on the usefulness of DST in their working practices. The documented behaviours, and viewpoints together with the beliefs of farmers, advisers, extension officers, industry representatives, and policy makers can be used during the initial phase of a co-production model for the development of an efficient DST in the field of agriculture.

Q-methodology can facilitate the exploration of various perspectives about a wide array of agricultural subjects, thereby supplementing the existing repertoire of research approaches. Moreover, it can serve as a potential pedagogical instrument, aiding stakeholders in comprehending the agricultural domain from a more comprehensive standpoint encompassing professional, cultural, and social dimensions. Lastly, Q-methodology can be employed in the formulation of policies governing the dissemination of cutting-edge tools like DSTs, thereby enhancing our understanding of the transfer of innovative practices to the agricultural sector and, consequently, bolstering the efficacy of innovation policies. This is similar to the findings of Ara et al. (2021) and Vecchio et al. (2022).

4.2 Needs and requirements

The statistical and sociodemographic information drawn from the sample and the analysis for each factor were important for the qualitative interpretation and were presented previously in Table 3.

The major points emerging from Factor 1 were associated with the cost of purchase and use of such tools and the education and training of end users on technology advancements so that they can become part of their daily practices in relation to more sustainable farming. Rose et al. (2016), also refer to the issue of cost, giving two alternatives for the likelihood of use, one when there is a funding scheme to support purchase and use or the likelihood of the tool being inexpensive. Venkatesh et al. (2012) also add price value as a predictor of behavioural intention to use technology while Clark et al. (2013) give a different dimension regarding cost and its influence on user involvement in the development of the DSTs.

As far as education and training were concerned, while this research focuses on a specific area in the Mediterranean basin, it is argued that the results can be extrapolated to other areas. As Lundstrom (2016) suggests intuitive experience-based knowledge is equally important to technology that enables more sustainable farming. That makes the need for education and training related to contemporary technology advancements necessary for farmers to remain up to date. The development of a skillset that will allow the proper use of such technologically advanced tools (Bournaris & Papathanasiou, 2012) is considered necessary for the improvement of the adoption rate of DSTs, (Bournaris & Papathanasiou, 2012). Zhai et al., (2020) also suggested that these skills should not be ignored by DST developers.

Factor 2 participants expressed a more technocratic view in relation to the adoption and use of DSTs focusing on functionality and performance. As noted in Table 3, all Factor 2 participants held a university degree related to agriculture, and all but one of them worked in the respective ministry for the central government or the regional administration. Knowledge in the field and professional interactions influence choices such as personal beliefs, political affiliations, and/or external pressures are equally crucial and can influence choices. The themes that emerged were the importance of DST use and adoption for the management approach of farm businesses and the need for multiple benefits for all categories of stakeholders involved. Participants also recognised the difficulty of accessing information about practices farmers undertake daily. They also noted a requirement and an opportunity for DSTs to be used in more routine situations rather than just in occasional exceptional circumstances.

The benefits emerging from the use and adoption of DSTs are multidimensional. The achievement of better decisions and/or a better decision-making process was not always the goal. In many cases, the benefits for stakeholders could be identified as greater reliability, better communication, better coordination, or even the achievement of competitive advantage. In certain instances, the outcome as well as the process remain unaffected; however, the system functions to record the quality of the process in a manner that could potentially persuade stakeholders of the accuracy of a decision (Pick, 2008). Sophisticated decision support systems can be very useful in agriculture, but their utility must be considered from a number of perspectives. First, the limits of current access to information for the profession must be considered. Second, the diversity of aspects of sustainability, including economic, social, and environmental perspectives, must be incorporated into the planning and design process. Finally, it is important to consider who the end-user will be (Ellis & Schoeneberger, 2004; Yousaf et al., 2023; Zhai et al., 2020).

About the management process of each user, the only hypothesis that can be made regarding the farmers' decision-making processes and management approach, is that each farming system differs to some degree in terms of management approach. In many instances, the effective adoption of DSTs may require a considerable change to a given farming system but would probably benefit farmers to switch towards more sustainable farming businesses (Gouttenoire et al., 2011).

In relation to Factor 3, the main points that emerged were the relevance to the user and the usefulness of the DSTs. Advisers were the most prevalent among the participants associated with this factor. Arnott and Pervan (2005) identified that the low practical relevance of DST research is not only due to farmers' passivity and attitude but is also a symptom of research inertia. This was also the main concern of advisers who suggested there was no research connected to the production process and the effective dispersal of information to end-users either by research institutes or through demonstration in experimental farms. It was noted that research institutes used to operate throughout the countryside and were integrated with farmers' communities but now appear largely inactive or no longer there and demonstration farms are rare to find.

Access to agronomic advice and information to the farmer is important in decision-making for a sustainable farm business. Farmers need different types of information from various sources to refine existing practices and adopt new more sustainable technologies (Nikam et al., 2022). This includes data on weather patterns, pest control, crop selection, soil health, water management, market trends, and more. The respondents in this factor stressed the absence of information from the state and its agencies noting that many of the research and extension facilities were non-operational and obsolete. Nikam et al. (2022) noted that depending on the time and situation, farmers require various types of information throughout the production process. Having access to accurate and up-to-date agronomic advice and information about the farming profession is crucial for making well-informed decisions that contribute to a sustainable farm business (Parmar et al., 2019). To promote sustainable farming, authorities must re-establish research facilities and disseminate agronomic advice to farmers. Providing information to farmers can increase productivity and promote sustainable practices that benefit the environment and livelihoods (Muhie, 2022).

Factor 4 was constituted mainly of industry representatives, see Table 3. They were focused on farmer compliance during the production process to regulations and legislation. The participants in the fourth factor noted that DSTs can improve managerial decision-making and assist their decision-making regarding soil properties. Diverging opinions were expressed regarding DSTs matching the skills and habits of different age groups (Lutuli, 2019), and that a more comprehensive and inclusive theoretical psychological foundation may cause DST research to be more aligned to practical applications. By broadening the theoretical foundation of psychology, the developers of DSTs may be able to better understand the practical implications of their work and develop more effective and useful applications of DSTs. The uptake of innovation also emerged as members of this group agreed that it can offer solutions to productivity, input efficiency, and the adoption of smarter farming approaches to increase the sustainability of farming systems. This agrees with the findings of Eastwood and Renwick (2020), Eneji et al. (2012), and Masi et al. (2022).

The management options that DSTs provide to their users allow them considerable flexibility for implementing and improving management strategies e.g., for crop rotations and pesticide management (Jones et al., 2003; Pahmeyer et al., 2021; Young et al., 2021). The same can be argued for assessing soil properties and allowing the appropriate cultivation and fertilisation to be programmed and implemented.

The support and improvement of managerial decision-making are documented by Arnott and Pervan (2005, 2014) in terms of contemporary professional practice. Others have noted that DST facilitates the implementation of improved farm management practices (Carberry et al., 2002), (Kragt & Llewellyn, 2014), and (McCown et al., 2009). In terms of relevance, participants think that there is no issue between research and practice and that the reference theories used did not constrain DST projects and what have been thought to be feasible and important similarly suggested by Arnott and Pervan (2005).

In relation to age and the ingrained skills and decision-making habits, (Rose et al., 2016) the participants did not feel this was a major issue related to future adoption and use of DSTs. This is contrary to the findings of Rose et al. (2016) who noted that age was probably a significant determinant of DST adoption. Lindblom et al. (2017), recognises that ingrained skills and habits, which may be more so in older farmers, were related to a lower adoption rate of DSTs. Similarly, age was also found to have a negative effect on smartphone DST adoption (Michels et al., 2020).

Participants related to the fifth factor (farmers, see Table 3) had positive opinions concerning farmers actively being involved in the processes of agricultural technology development and that DSTs had the potential to have multiple benefits for the stakeholders involved. However, some also noted that a DST must match the skills and habits of different age groups (Rose et al., 2016) and that subsidies could not act as an incentive to encourage more sustainable farming.

Kernecker et al. (2020) note that DST adoption and use was based on the active engagement of farmers in the processes of agricultural technology development. This facilitated

Table 5 Needs and requirements of end users

1	Cost: The tool must be inexpensive to acquire and use
2	Education/training: End-users need the appropriate training to apply new technologies
3	Functionality: The tool must be related to the farmer's actual practices regarding management, soil properties, and crop practices
4	Performance/benefits: The tool must perform well and have multiple benefits for the stakeholders utilising the tool
5	Relevance: The tool must be relevant to the individual farm circumstances
6	Usefulness: The tool must consider the dynamic nature of the farm business
7	Applicability: The tool should be usable at a range of scales of farming
8	Innovation uptake: End-users must be open-minded about the use of new technologies
9	Active involvement: There is considerable benefit from involving farmers in agricultural technology development
10	IT skills: End-users must continue to develop their IT Skills

the persuasion of farmers by demonstrating the availability and accessibility of suitable technologies. It mitigates resilience solely on peer-to-peer communication as the main source of information and can change their perceptions regarding innovation processes such as the use of DSTs.

To achieve this, there is a need for training on new technologies (Saiz-Rubio & Rovira-Mas, 2020) and the realisation that the science incorporated in these tools and other benefits can be more easily accessible from farmers and their advisers through their use (Jakku & Thorburn, 2010). Multiple benefits such as precision farming and resource management, crop health monitoring and management, market insights and demand forecasting, and financial planning and budgeting, were considered necessary for the stakeholders in a study by Demetriou et al. (2012). Most of the crops farmed in the study region are market goods in the sense that they do not depend on subsidies. This could be one of the reasons why the two farmers do not concur with Sorensen et al. (2010), who advocate that subsidies can act as motivators for sustainable farming practices. Additionally, the lack of awareness concerning farm sustainability in the area, as reported in our preceding research (Iakovidis et al., 2023), may serve as another explanation.

Divergent opinions regarding the role of subsidies in promoting sustainable farming practices were observed among different stakeholders. Farmers, in general, did not consider subsidies as a strong incentive towards sustainable farming. However, extension officers, industry representatives, and policy makers generally believed subsidies were a motivator for enhancing farm sustainability.

The differing perspectives on subsidies highlight the complexity of the issue and the need for a comprehensive understanding of the motivations and barriers to the adoption of sustainable farming practices. The research findings emphasise the importance of considering multiple stakeholder perspectives when designing effective Decision Support Tools (DSTs) for the agricultural sector.

The needs and requirements identified in this research provide guidelines for the design of effective DSTs, see Table 5. The findings presented align with other research studies and that confirms the importance of stakeholders' viewpoints and beliefs on the subject. Cost appears to be a crucial determinant and funding for initial purchase and use was considered imperative from the participants. Relevance to the user was found to be important as well as the need for the DST to be adaptable to the individual farm circumstances.

Incorporating the DSTs into the daily decision-making process of the users was favourably received. It was characterised as pivotal and perceived to enhance their decision performance on technical and managerial aspects while not disturbing their daily routine.

The need for enhanced farm performance and additional benefits for the stakeholders was also stressed. The tool must work well, perform as promised, and offer multiple benefits to all implicated stakeholders. To tackle technology development and innovation uptake, there is a need for positive and regular engagement in education and training. Active involvement in the DST development processes is seen as beneficial, for instance via co-production where all stakeholders are involved, and collaborate in order to determine problems and identify and produce solutions. Regular and appropriate access to agronomic advice and information was also stressed, with a belief that currently there is not easy access to sources of knowledge and information.

Finally, the issue of financial support and its role in the transition to sustainable farming was a key issue. Farmers did not consider subsidies as an incentive towards sustainable farming while extension officers, industry representatives, and policy makers assessed it positively as a motive for enhancing farm sustainability.

5 Conclusions

The paper suggests that the initial involvement of stakeholders utilising a participatory approach is a desirable requirement for an effective design of a DST. The Q-methodology approach was employed to facilitate a comprehensive comprehension of the viewpoints and requirements of the various groups of individuals involved in the matter (Oksnebjerg et al., 2019). The research affirms that the utilisation of Q-methodology can function as the initial phase of a comprehensive assessment of end-user requirements within a collaborative framework for the development of a proficient DST in the field of agriculture. The paper emphasises the importance of understanding the factors influencing the adoption and use of DSTs by farmers and advisers and the need for site-specific agronomic management strategies for agricultural growth.

The key messages from the research are:

- *Farmer-Centric Approach* Ensure that DST design and implementation prioritise the needs and aspirations of farmers and advisers. Engage with stakeholders from diverse backgrounds to understand their unique challenges and requirements.
- *User-Friendly Tools* Develop DSTs that are intuitive, user-friendly, and accessible to farmers and advisers with varying levels of technological expertise. The tools should provide practical solutions that align with farmers' daily operations.
- *Demonstration Farms* Establish demonstration farms where farmers can observe and experience the benefits of incorporating DSTs. This practical, hands-on approach can enhance farmers' understanding and motivation to adopt sustainable practices.
- *Knowledge Exchange* Facilitate knowledge exchange and learning among farmers, advisers, and researchers. This exchange can help disseminate best practices and foster a collaborative learning environment.
- *Local Context Considerations* Tailor the DSTs to suit the local context, considering factors such as agro-climatic conditions, available resources, and socio-economic realities. Generic solutions may not be as effective as context-specific ones.

- *Financial Support* Acknowledge the financial constraints faced by farmers and explore ways to provide financial support for DSTs. Incentives, subsidies, or low-cost financing options can encourage wider adoption.
- *Capacity Building* Offer training and capacity-building programs to familiarise farmers with the DSTs and build their skills in using them effectively.
- *Policy Advocacy* Advocate for supportive policies and regulations that promote the integration of DSTs and sustainable farming practices. Engage with policy makers to highlight the benefits and encourage their adoption.

The Q-factor analysis identified five factors that provide insights into the needs and requirements of end users in the adoption and use of DSTs in the agricultural sector. These factors represent different perspectives and views expressed by participants in the research, offering a comprehensive overview of the predominant opinions and priorities.

The factors derived from the Q-factor analysis can inform the development and optimisation of DSTs by considering the varying perspectives and priorities of different stakeholders in the agricultural sector. By incorporating the insights from the factors, DSTs can be tailored to address the specific needs and requirements of end users, enhancing their effectiveness and adoption in the agricultural sector.

Furthermore, it is essential to underscore that the methodology employed in this research serves as a robust foundation for extrapolating findings to diverse agricultural contexts globally. Notably, the study's key findings underscore the imperative of customizing DSTs to local contexts, factoring in agro-climatic conditions, available resources, and socio-economic realities. This acknowledgment that generic solutions may not be as effective as context-specific ones underscores the adaptability of the research methodology. Therefore, the methodology is not only readily applicable to context-specific circumstances globally but also reinforces the recommendation to consider local factors for the findings to accurately represent the area and agricultural systems under study. In essence, the study's approach not only recognizes potential similarities but actively advocates for a nuanced understanding of local variations, thereby fortifying its applicability and relevance on a broader scale.

Overall, the paper provides practical implications for the design and development of DSTs in agriculture that can enhance the decision-making of farmers and advisers, safeguard the natural resource base, enhance resilience and food security, and promote sustainable production systems. By incorporating these strategies, the effective design of DSTs can bridge the gap between them and farmers' needs, leading to greater adoption and the realisation of the potential benefits of sustainable farming practices.

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Declarations

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Ethical approval I confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country.

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