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ASSESSING THE DESIGN OF A MODEL-BASED IRRIGATION ADVISORY BULLETIN: THE IMPORTANCE OF END-USER PARTICIPATION†

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ABSTRACT

Successful uptake of modern irrigation techniques and farmer decision support tools are necessary to promote the sustainable use of water resources. However, many of these tools fail to receive sufficient uptake from farmers to have a significant impact on water saving. End-user participation during tool development can increase the adoption rate as the tool becomes more usable. In the Segura River Basin of Spain, an irrigation advisory bulletin was designed to support farmers in their irrigation planning and scheduling. The bulletin was distributed to innovative farmers who are early adopters of modern irrigation technology. A formative evaluation procedure was applied to assess the acceptability of the bulletin against a number of non-adoption criteria, including irrelevance, inflexibility, inaccessibility, lack of confidence and institutional and political barriers. Feedback from the pre- and post-trial run surveys revealed that there were discrepancies between perceived and actual information needs by farmers, which include seasonal influences, water quality, salinity levels and crop life cycle. We demonstrate and argue the importance of assessing end-user needs again after the implementation of the decision support system in order to limit the risk of non-adoption. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: decision support tool; adoption; water resource; barriers; agriculture; citrus

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RÉSUMÉ

L'assimilation réussie des techniques d'irrigation modernes et des outils d'aide à la décision des agriculteurs sont nécessaires pour promouvoir l'utilisation durable des ressources en eau. Cependant, beaucoup de ces outils ne parviennent pas à recevoir une assimilation suffisante des agriculteurs pour avoir un impact significatif sur l'économie d'eau. La participation de l'utilisateur final au cours du développement de l'outil peut augmenter le taux d'adoption de l'outil, qui devient plus utilisable. Dans le bassin de la rivière Segura en Espagne, un bulletin d'alerte d'irrigation a été conçu pour aider les agriculteurs dans la planification la programmation de l'irrigation. Le bulletin a été distribué aux agriculteurs innovateurs qui sont les premiers à adopter la technologie d'irrigation moderne. Une procédure d'évaluation formative a été appliquée pour évaluer l'acceptabilité du bulletin contre un certain nombre de critères de non-adoption, y compris la non-pertinence, la rigidité, l'inaccessibilité, le manque de confiance et les obstacles institutionnels et politiques. Les retours d'information sur les enquêtes pré et post-test de fonctionnement révèlent des divergences entre la perception et la réalité des besoins en information des agriculteurs, qui portent sur les influences saisonnières, la qualité de l'eau, les niveaux de salinité et le cycle de vie des cultures. Nous démontrons et soutenons l'importance d'évaluer les besoins de l'utilisateur final après la mise en œuvre d'un système d'aide à la décision afin de limiter le risque de non-adoption. Copyright © 2014 John Wiley & Sons, Ltd.

MOTS CLÉS: outils d'aide à la décision; adoption; ressources en eau; obstacles; agriculture; agrumes

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†Évaluation de la conception d'un bulletin d'alerte irrigation basé sur un modèle: l'importance de la participation de l'utilisateur final.

INTRODUCTION

The increased level of water scarcity in the Mediterranean region has led to the consideration and in some cases implementation of water-saving technologies and management options. Drip irrigation, for example, is widely adopted in many irrigation districts of the study area. Alcon *et al.* (2011) provide a detailed summary of the history of irrigation techniques in the region as well as information on current irrigation techniques used. Emerging irrigation strategies, such as regulated deficit irrigation (RDI), can help farmers to achieve significant water savings. However, this type of technique generally requires information on location-specific soil and crops to control for risks (e.g. Fereres and Soriano, 2007; Geerts and Raes, 2009; Alcon *et al.*, 2013). This can be obtained by implementing measurement and control systems that monitor soil or crop responses to irrigation (precision irrigation) but should be complemented by up-to-date information on weather and crop demand predictions versus irrigation scheduling options (e.g. Rao *et al.*, 1992; Steppe *et al.*, 2008).

In Spain, agro-meteorological information is made accessible by government agencies, agricultural extension services and research institutions. Currently, farmers in the Segura River Basin can access geo-referenced information on irrigation water needs provided by the regional agro-meteorological public service (Erena *et al.*, 2000). This information is based on historical weather data from a network of agrometeorological weather stations throughout the region.

Despite the significant investment in time, know-how and data collected to make various types of information available to farmers, non-adoption still occurs, as evidenced by significant water losses due to over-irrigation and non-optimal timing and dosing of irrigation (Lorite *et al.*, 2004; Knox *et al.*, 2011). This may stem from the fact that the information system provided to farmers is not meeting their actual needs. The problem is not exclusive to Spain. In the USA, the use of computer simulation models to support irrigation scheduling is also limited, with only around 2% of irrigated farms using these types of tools (United States Department of Agriculture (USDA), 2009).

The lack of adoption is due to the fact that a number of these advisory services still follow a top-down process, giving little consideration to farmers' preferences for the type of information required and the ease of interpreting instructional information provided. Conceptually, the involvement of end-users in every development phase of a decision support tool is considered fundamental in order to produce a tool that meet end-users' needs (Uran and Janssen, 2003; Matthies *et al.*, 2007; Lautenbach *et al.*, 2009; Santoro *et al.*, 2013). As a matter of fact, participatory approaches have been designed to respond to the shortcomings of the conventional top-down approach to decision making (VSO, 2009). End-user participation encourages knowledge sharing, mutual learning, and enables the design of a tool that represents the interests of 'the people' the tools are supposed to serve (White and Pettit, 2004; VSO, 2009). To meet end-user needs, the tool should be interactive, flexible and adaptable, and have an easy user interface. Most importantly, it should help end-users make decisions in a complex decision-making process.

Figure 1 presents the widely followed life cycle for developing a decision support tool based on the tool proposed by Turban *et al.* (2004). The process incorporates a feedback loop where end-user feedback from the post-implementation phase is used to inform and modify the planning, analysis and design phase. Based on evidence from the irrigated agriculture sector in Spain, where improvements in irrigation planning have not been achieved despite the distribution of georeferenced information on irrigation water needs to farmers, we believe the problem stems from the fact that

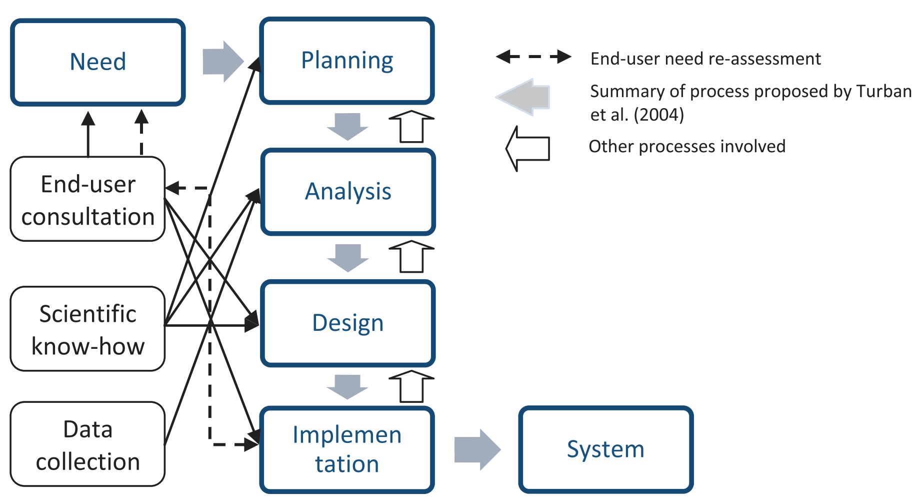

Figure 1. Decision support tool development life cycle and elements (based on Turban *et al.*, 2004)

end-user post-implementation feedback has not been considered in the information system design process. This can be a critical hindrance to the widespread use of the tool later on as end-users are not completely satisfied with what the tool delivers.

There are a number of criteria that have been used to measure the success of a decision support system (DSS). Hung *et al.* (2007) summarized that there are two broad categories for measuring DSS success: process-orientated and outcome-orientated. Process-orientated is measured against the frequency and length of system usage while outcome-orientated is measured against performance and user satisfaction (Hung *et al.*, 2007).

In this paper, we applied an outcome-orientated approach to identify the factors that may lead to non-adoption of a weekly irrigation advisory bulletin, which is a paper-based irrigation advisory service that provides farmers with information on irrigation decision making. Specific focus is given to measuring farmers' subjective evaluation of the usefulness of the irrigation advisory bulletin, as well as to capturing any changes in farmers' needs about what they expect the tool to deliver in order to meet their irrigation needs. A formative evaluation procedure was applied to obtain farmers' feedback on the advisory bulletin during its design and trial run in drip-irrigated citrus farms in the Segura River Basin, Spain. Farmers' responses are assessed against Walker's (2002) non-adoption criteria, namely, irrelevance, inaccessibility, inflexibility, lack of confidence and institutional and political barriers. Farmer feedback is then used to inform how the bulletin can be improved in order to better meet the needs of the end-user.

The objective of this paper is twofold. First, we propose a design of an irrigation advisory bulletin that can assist farmers in their irrigation decision-making process based on end-user feedback pre- and post-implementation of the tool. Second, we demonstrate the importance of incorporating end-user feedback post-implementation of the decision support tool to foster the actual uptake of the bulletin in drip-irrigated citrus farms in the Segura River Basin, Spain, in the future.

Design of the weekly irrigation advisory bulletin

The weekly irrigation advisory bulletin joins up different pieces of up-to-date information into a single document to support farmers in their weekly decisions on irrigation planning. The bulletin contains: (i) 7-day weather forecast information, including forecast crop water needs; (ii) options for irrigation dose and frequency to meet the forecast demand, and their impact on percolation and available soil water; (iii) past information (last year and last week) on actual irrigated amounts compared to predicted local crop water requirements. The information contained in the bulletin was decided through a consultative process between researchers and target end-users (e.g. farmers and agricultural advisors).

Upon consultation with the end-users during the design phase of the bulletin, which is discussed in more detail below, the end-users wanted the bulletin to provide information at farm level. Specifically, the bulletin design should take into account information about farm plot size, soil characteristics, citrus variety and density. This synthesized information source should enable end-users to consider various factors jointly when making decisions on the appropriate amount of irrigation water applied each week. An updated version of this bulletin is provided every week. The end-users agreed to receive a copy of the bulletin via email. Additionally, the end-users consented to sending their actual irrigation schedule back to the researchers each week as feedback information.

The principal considerations for the design of the bulletin were to provide clear-cut and uncomplicated information using concepts farmers are supposed to be familiar with and tailored to the corresponding plot. The bulletin provides local on-farm information, but does not provide any predictions or indicators of off-farm water supply as this information depends to a greater extent on political decisions. The objective was to include information that could be synthesized based on existing data sets, in order make it easily transferable to other regions. The methodological procedures for the bulletin components are explained in the following sections.

Weather and crop water demand forecasts

The application of short-term weather forecasts for irrigation scheduling has been demonstrated by several authors to benefit crop production (Hashemi and Decker, 1969; Gowing and Ejieji, 2001; Wang and Cai, 2009). For the bulletin, weather forecasts are extracted weekly from the Spanish National Meteorological Agency (AEMET). The following 7-day forecast information is used for the bulletin: (i) rainfall amounts; (ii) minimum and maximum temperatures; (iii) cloudiness; (iv) wind speed. Daily weather and evapotranspiration forecasts (*FORECAST*) are represented in the bulletin visually (Figure 2). Temperature forecasts are used for the calculation of the reference evapotranspiration (ET_0) for each day of the week, using the method described by Hargreaves and Samani (1985).

The following step was to calculate the standard crop evapotranspiration for a specific crop (ET_c) by multiplying ET_0 by a crop coefficient, K_c, which is an empirical parameter that accounts for the physiological and structural differences between the actual crop and the grass-like reference surface assumed for the calculation of ET_0. For operational applications, this approach is often preferred because it only requires phenological and standard meteorological data

	25-Mar	26-Mar	27-Mar	28-Mar	29-Mar	30-Mar	31-Mar
Rainfall (mm)	0	0	15	0	0	0	0
ETo (m3/Ha)	35	32	16	35	29	27	35
ETc (m3/Ha)	**17**	**16**	**8**	**18**	**15**	**14**	**17**

Figure 2. Table of daily weather and evapotranspiration forecasts (*FORECAST*)

while providing acceptable ET_c estimates compared to physically based modelling and field measurements. Crop coefficients used are the recommended values by FAO-56 (Allen *et al.*, 1998), and were adjusted using local information required from the farmer on citrus variety, ground cover and tree density. The daily forecast ET_c is also represented visually by means of a watering can, filled according to its value.

Impact of irrigation scheduling options

In addition to the prediction of crop water demand for the following week, the bulletin provides information on how different irrigation scheduling options could affect two parameters of interest: (i) the amount of water percolating to the aquifer; (ii) the minimum simulated fraction during the 7-day forecast period of total available water (i.e. the difference between water content at field capacity and permanent wilting point). Both variables were calculated using the agro-hydrological soil–water–atmosphere–plant (SWAP) model (Kroes and Van Dam, 2003). The SWAP model simulates the transport of water, solutes and heat in unsaturated and saturated soils. The model is designed to simulate flow and transport processes at the field scale level. The soil hydraulic parameters for the SWAP model were derived using the pedotransfer functions proposed by Schaap *et al.* (2001) based on soil texture. Soil texture for each site was extracted from soil maps with a high spatial resolution of 25 m, which were produced by interpolating point samples using various environmental proxy variables (Pérez-Cutillas and Barberá, pers. comm., 2012). For three sites in the area, detailed soil profile and hydraulic data were available to verify that the estimates based on the soil texture maps produce similar output for the bulletin as those based on sampled soil data.

The models for each site were run iteratively over the forecast period with different scheduling options, i.e. with different irrigation intervals and doses. To show how the options affect the two parameters of interest, a summary table of irrigation scheduling options (*OPTIONS*) is included in the bulletin (Figure 3). Relative percolation was calculated as the average percolation divided by the water input (irrigation + rainfall) for the 7-day forecast period. To show the impact on soil moisture, the minimum is taken of the readily available water (FC-WP in the root zone) of the forecasted period. The two output parameters are also visually represented in the bulletin. The dots in Figure 4(a) and (b) show the outcome of the combination of various irrigation intervals (days) and dose ($m^3\,ha^{-1}$) on relative percolation (*PERCOLATION*) and soil water levels (*SOILWATER*), respectively. The orange to red colours (or grey to dark grey in black and white) in Figure 4(a) indicate a loss to the aquifer. The light to dark blue colours (or light grey to dark grey in the top left-hand quadrant) in Figure 4(b) indicate excess water in the soil while the light to dark brown colours (or light grey to dark grey in the bottom right-hand quadrant) indicate a soil water deficit that can affect crop growth and production. Hence, for both graphs, the ideal irrigation intervals (days) and dose ($m^3\,ha^{-1}$) would be the white (uncoloured) areas.

Farmers can use the information in Figure 4(a) and (b) to arrive at a suitable irrigation dose and frequency for their farm, taking into account possible water losses and crop water stress.

Comparison of irrigated versus crop water demand

The following component of the bulletin consists of a representation by means of tables and graphs on how the applied irrigation amounts of the particular farmer compare with the crop water requirements calculated based on the closest weather station data and the local crop coefficients (Figures 5–7). For short-term decision making, the bulletin includes a graphical representation of irrigated amounts versus crop water requirements of last week (*LWEEK*). For long-term planning, a summary table of monthly irrigation levels (*SUMMARY*) covering the last 12 months is provided. Also, a graphical comparison of monthly irrigated amounts and crop water requirements (*COMPARISON*) is included. Both monthly and weekly information can be of use to the farmer to plan irrigation for the entire season while at the same time being responsive to current weather conditions using up-to-date information. The farmer is able to revise the decisions made each week and adjust the irrigation schedule for the subsequent weeks if needed, while keeping under consideration the full planning horizon.

Irrigation interval	Irrigation dose	Evapo-transpiration	Minimum available water	Relative percolation
Days	m3/ha	%	%	%
1	18	100	92	1
2	36	100	91	1
3	54	100	89	2
4	73	100	90	7
5	91	100	72	12
6	109	99	48	17

Figure 3. Table of irrigation scheduling options (OPTIONS)

BULLETIN EVALUATION METHODOLOGY

In a discussion paper on the success and failure of decision support tools in rural resource management, Walker (2002) argued that there are three outcome-orientated factors that cause decision support-based projects to fail: non-delivery, non-adoption and negative impacts on decision making. Non-delivery refers to the failure to produce tools that fully meet the original specifications. Non-adoption occurs for a number of reasons: (i) *irrelevance*—is about the relevance of the information provided and the ability to deliver what the end-users require. The tool is irrelevant if it is not closely aligned with the real decision-making process; (ii) *inflexibility*—conceptually sound and well-designed tools may still face non-adoption because they do not address a sufficient range of tasks to be useful for the end-user (Walker, 2002); (iii) *inaccessibility*—conceptual inaccessibility is when the information provided is too difficult to understand. The tool is physically, technically and conceptually difficult to access; (iv) *lack of confidence*—is the lack of user confidence in the reliability of the tool. Lack of confidence in the tool can lead to non-adoption despite it being able to meet all the deliverable requirements. The purpose of these questions is to identify whether the end-users have sufficient confidence in the tool to follow the recommendations; and (v) *institutional and political barriers*—the external factors that hinder the adoption process. Finally, the tool may distort the decision-making process and lead to negative outcomes.

Formative evaluation

In order to improve the bulletin design and meet user requirements, a formative evaluation procedure was applied to assess the acceptability of the bulletin against a number of outcome-orientated non-adoption criteria, including irrelevance, inflexibility, inaccessibility, lack of confidence and institutional and political barriers. The evaluation procedure was conducted in the form of individual and small group interviews and field trial runs. A formative evaluation procedure is commonly used to improve the design of instructional materials, such as textbooks, by means of identification and remediation of problematic aspects, through a consultative process with experts and end-users. It is typically conducted during the development and improvement stage of the

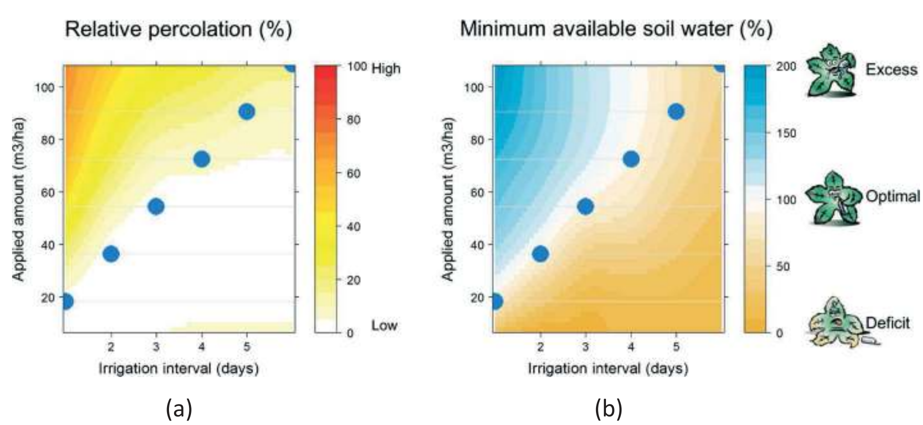

Figure 4. The impact of different irrigation scheduling options (dose and frequency) on (a) the mean relative percolation (*PERCOLATION*) and (b) the minimum available soil water (*SOILWATER*)

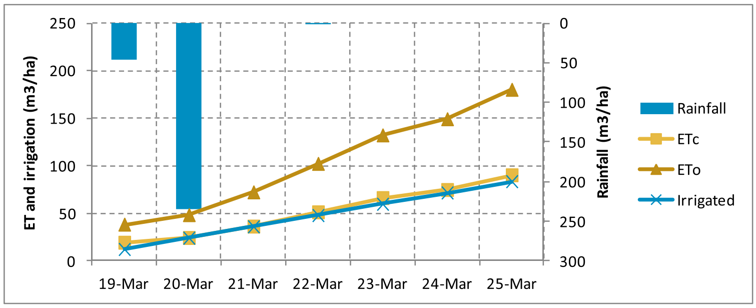

Figure 5. Irrigated amounts versus crop water requirements of last week (*LWEEK*)

instructional material (Scriven, 1991). The aim of the formative evaluation framework is to identify and remediate outcome-orientated factors that lead to non-adoption of the irrigation advisory bulletin.

Sample selection and recruitment

In addition to farmers, agricultural advisors in the Segura River Basin were selected to participate in the group interviews. These farmers and agricultural advisors were selected following the advice from an extension service agent who categorized them as innovative or early adopters of new farming techniques compared to other farmers in the region. Agricultural advisors, although not farmers, play an important role in influencing farmers' decisions about farming and irrigation. Farmers with the financial means often use the expert advice of agricultural advisors on the optimal level and timing of irrigation. Hence, these agricultural advisors need information from the irrigation advisory bulletin as much as any farmer who is making irrigation decisions him/herself. The advisors also have significant influence on farming activities in general because farmers who use their services rely heavily on their advice. And most farmers who employ the services of agricultural advisors are early adopters because they can afford to make the financial investment. As such, these agricultural advisors are perfect candidates for the study as they require similar types of information to farmers for decision making.

	Irrigated		Rainfall	ETo	ETc	Kc*
Month	l/tree	m3/ha	mm	m3/ha	m3/ha	-
Feb-11	1114	265	6	607	303	0.50
Mar-11	1606	382	66	715	347	0.49
Apr-11	2280	543	23	1046	497	0.48
May-11	2927	697	11	1339	619	0.46
Jun-11	3938	938	21	1598	719	0.45
Jul-11	4948	1178	2	1813	816	0.45
Aug-11	4223	1005	0	1734	780	0.45
Sep-11	2280	543	14	1248	562	0.45
Oct-11	1606	382	4	831	399	0.48
Nov-11	907	216	39	421	219	0.52
Dec-11	699	167	15	385	212	0.55
Jan-12	492	117	25	372	193	0.52

Figure 6. Summary table of monthly irrigation levels (*SUMMARY*)

There were two reasons for selecting innovative and early adopting farmers and agricultural advisors. First, each bulletin is farm-specific. Therefore, budget and time constraints limit the number of farmers and agricultural advisors that could participate in the trial run. Second, to compensate for the small number of innovators and early adopters , agricultural advisors were selected. According to Rogers (2003), innovators have the ability to understand and apply complex technical knowledge, are able to cope with a high degree of uncertainty about innovation, are risk-takers and enjoy the rush from risk-taking. Additionally, innovators are more likely to be opinion leaders (Ruvio and Shoham, 2007), have greater access to financial resources and have larger social networks (Dickerson and Gentry, 1983). As such, they are the first point at which innovation and new technologies spread. Since the bulletin is a relatively new technology for farmers in this region, it was deemed appropriate to select innovative farmers and agricultural advisors as the sample for this study.

During the recruitment phase, a number of farmers and agricultural advisors expressed their interest in participating in the group interview but were not able to attend. As such, these farmers were contacted later for a personal interview. A total of 20 citrus farmers and agricultural advisors were invited to participate in the interviews.

Pre-trial run interviews

The personal and group interviews were conducted in January 2012. The group comprised five farmers and five agricultural advisors. Each interview lasted approximately 1 h. At the beginning of each interview, the DSS developers explained the functionality and benefits of the provided information to the participants. An explanation was also given on how such information could be useful for optimizing water productivity and applying regulated deficit irrigation. The experts detailed how the participants can interpret and make use of the information for weekly irrigation decision making and for long-term planning. Then, the floor was opened to the participants for questions, comments or feedback that were noted and used afterwards to remediate issues that

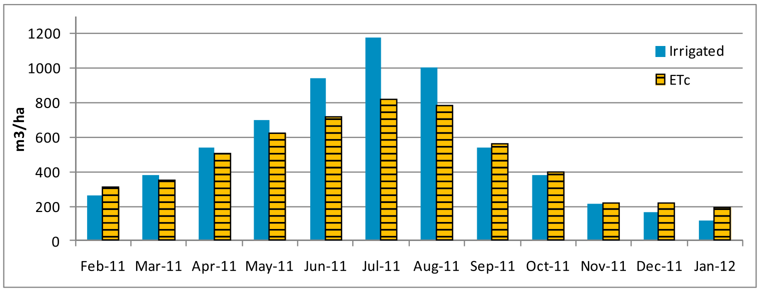

Figure 7. Monthly irrigation level and crop water requirements (*COMPARISON*)

were raised in the weekly bulletin. From the pre-trial run interviews, we were able to establish the types of information that participants needed for irrigation decision making.

Pre-trial run survey design

Before the commencement of the bulletin trial run, participants were asked to complete a short survey to assess how much they believed the information in the revised weekly bulletin would be useful to them and how the bulletin could help improve their productivity. This pre-trial run survey consisted of three sections. Each section contained seven-point Likert-scale questions (rating 1 = not useful at all, to rating 7 = very useful). The first section was designed to assess the participants' opinion about the usefulness of the information presented in the weekly bulletin. The second contained questions aimed at measuring their agreement about the benefits of adopting the bulletin, such as benefits associated with increased tree performance and fruit quality. The third contained questions to determine whether they were already using other sources of information such as that provided by the Agricultural Information System of Murcia (SIAM), and whether they would use the information in the bulletin in their irrigation decision-making process.

Post-trial run survey design

After the bulletin trial run finished, participants were sent a follow-up survey about the bulletin. The objective of the follow-up survey was to assess whether they found the information in the bulletin useful, how often the information was actually used to support their irrigation decision and whether they would like to use the bulletin in the future. As these farmers and agricultural advisors were considered early adopters of irrigation technology, it was important to find out whether their experiences in using the bulletin would lead them to use the bulletin in the future and to recommend it to other farmers and agricultural advisors.

For consistency, the format of the follow-up survey mimicked the pre-trial run survey with some minor variations. The first section contained questions on the participants' opinion about the usefulness of the information provided by the bulletin, how often they used the information for decision making and whether they found the information difficult to understand. Additionally, the participants were asked to give their opinion on how the information can be improved in open-ended questions. The second section contained seven-point Likert-scale questions to assess the factors that may have influenced their decisions to use the bulletin's information in the future.

Participants were given an option as to how they would like the questionnaires and the bulletins to be sent to them. All respondents agreed to receive both the questionnaires and the bulletins via email. However, a number of participants decided to reply to the questionnaires over the phone.

Statistical analysis

A test of differences in group mean responses by profile (i.e. farmers versus agricultural advisors) was performed to test whether there are significant differences in their attitudes towards the bulletin before and after the trial run. Accounting for the fact that the sample size is smaller than 30, a non-parametric Kruskal–Wallis rank test (Kruskal and Wallis, 1952) for differences between medians was performed to test for the response differences between farmers and agricultural advisors. The Kruskal–Wallis test is used when the variables of interest do not meet the normality assumption of an ANOVA. Hence, it is a non-parametric analogue of a one-way ANOVA. The response differences between rounds were also tested using the non-parametric Wilcoxon signed-rank test (Wilcoxon, 1945).

RESULTS

A total of five farmers and five agricultural advisors participated in the pre-trial run survey. The number dropped to four farmers and four agricultural advisors in the post-trial run survey due to two participants not being able to continue further. This is equivalent to a response rate of 40–50%.

Test of profile differences on usefulness ratings

The non-parametric Kruskal–Wallis rank test for differences between medians suggests that in the pre-trial run survey both farmers and agricultural advisors rated the level of usefulness of each type of information the same bar one item—*COMPARISON*. Agricultural advisors found *COMPARISON* more useful than farmers. The differences in response between the two groups were significant at the $p < 0.05$ level.

Results from the post-trial run survey suggest that farmers and agricultural advisors were mostly in agreement with the level of usefulness for all types of information bar one—*PERCOLATION*. The differences in the ratings was significant at the $p < 0.05$ level. Table I presents summary statistics from the usefulness rating of the bulletin information pre- and post-trial run by group.

Test of profile differences on acceptability ratings

In the post-trial run survey, participants were asked to rate their level of agreement on whether they would recommend the bulletin to other farmers and agricultural advisors; change their irrigation schedule based on the bulletin information; access the bulletin if it were available on the internet; and pay for the bulletin in the future (Table II). The non-parametric Kruskal–Wallis rank test for differences between medians suggests that farmers and agricultural advisors only significantly differed (at $p < 0.05$ level) in their ratings towards recommending the bulletin to other farmers and agricultural advisors. Farmers were more likely than agricultural advisors to recommend the bulletin to others.

Test of survey round response differences

Assuming there was a general homogeneous viewpoint between farmers and agricultural advisors towards the usefulness of the bulletin, a test of pooled (farmers and agricultural advisors combined) mean response differences between rounds was performed. *SUMMARY* and *PERCOLATION* were excluded from this test as usefulness ratings between the two end-users were significantly different, thus should not be pooled together. Table III provides summary statistics of the pooled usefulness ratings for the pre- and post-trial run responses. Note that statistics for *SUMMARY* and *PERCOLATION* have been blanked out. The pooled test of usefulness ratings pre- and post-trial run indicated that *FORECAST, COMPARISON* and *SOILWATER* were rated higher in the pre-trial run survey than the post-trial run survey (at the $p < 0.1$ level for *FORECAST* and *COMPARISON* and at the $p < 0.05$ level for *SOILWATER*). Ratings for *LWEEK* and *OPTIONS* were not significantly different between rounds.

In the pre-trial run survey, participants rated *COMPARISON* and *FORECAST* to be the two most useful types of information. In the post-trial run survey, participants rated *COMPARISON* and *LWEEK* to be more useful than *OPTIONS, SOILWATER* and *PERCOLATION*. *FORECAST*, on the other hand, was no longer thought to be useful after participants had actually trialled the bulletin.

Formative evaluation

The farmers' and agricultural advisors' responses to the pre- and post-trial run were assessed against Walker's (2002)

Table I. Usefulness rating of the bulletin information before and after the trial run by group (on a scale of 1–7)

Item	Survey version (pre-/post-trial run)	Farmer				Agricultural advisor			
		n	Mean	SD	Med	*n*	Mean	SD	Med
SUMMARY	Pre	5	5	1.22	5	5	5.8	0.45	6
	Post	4	4.75	1.26	5	4	5.5	0.58	5.5
COMPARISON	Pre	5	5.6	0.55	6	5	6.6	0.55	7
	Post	4	4.75	1.26	5	4	5.5	0.58	5.5
LWEEK	Pre	5	5.2	0.84	5	5	5.8	0.45	6
	Post	4	5.25	0.96	5.5	4	5.5	0.58	5.5
FORECAST	Pre	5	5.8	1.1	5	5	6.6	0.89	7
	Post	4	4.25	2.06	4	4	5	1.41	4.5
OPTIONS	Pre	5	5.2	0.84	5	5	5.6	1.52	6
	Post	4	4.5	1.73	4.5	4	3.25	0.96	3.5
SOILWATER	Pre	5	5.4	0.89	6	5	5.4	1.52	6
	Post	4	4.75	0.96	4.5	4	3.25	0.96	3.5
PERCOLATION	Pre	5	5.2	0.45	5	5	5.4	1.82	6
	Post	4	4.75	0.96	4.5	4	3.25	0.5	3

SUMMARY = Summary table of monthly irrigation levels, *COMPARISON* = Graphical comparison of monthly irrigated amounts and crop water requirements, *LWEEK* = Graphical representation of irrigated amounts versus crop water requirements of last week, *FORECAST* = Daily weather and evapotranspiration forecasts, *OPTIONS* = Table of irrigation scheduling options, *SOILWATER* = The impact of different irrigation scheduling options (dose and frequency) on minimum available soil water, *PERCOLATION* = The impact of different irrigation scheduling options (dose and frequency) on the mean relative percolation.

Table II. Acceptability rating of the bulletin post-trial run group (on a scale of 1–7). 'Rate your level of agreement with these following statements'

	Farmer			Agricultural advisor		
	Mean	SD	Med	Mean	SD	Med
I will recommend the bulletin to other farmers	5.5	0.58	5.5	4.5	0.58	4.5
I will use this information to adjust my irrigation level in the future	5.25	1.71	5.5	6.25	0.96	6.5
I will try to access this information if it were available on the internet	5	2.83	6	5	0.82	5
I would be willing to pay for this information	4	2.58	4	2.75	0.96	2.5

causes of non-adoption. Responses from these participants before and after the trial run were collated and compared. A number of statements from the open-ended section of the follow-up survey are also presented.

Irrelevance A number of participants expressed their reluctance to use the bulletin because it was too general and did not apply to their particular farming operation. One participant, a farmer, in particular raised the issue of soil moisture and the relative effect on irrigation level in his particular area:

> 'The recommended irrigation level does not seem to be realistic for this area. At times in the past when soil moisture is high and irrigation should be cut back to control for diseases stemming from excess humidity, however, the bulletin recommends a high irrigation regime.'

This indicates that the tool is not closely aligned with the real decision-making process and could potentially be irrelevant to end-user needs.

Inflexibility In terms of the bulletin's ability to address a sufficient range of tasks to be useful for the end-user, suggestions provided by participants revealed that certain important sets of information were not incorporated into the bulletin. One participant, an agricultural advisor, found that the bulletin did not account for water quality, nor growth phase and harvesting periods.

> 'The last part where it talks about percolations, I think it is too general and the information is not adapted to the specific farm. Water quality should be an important factor. The crop cycles and the periods of harvest are not taken in account.'

Another participant, an agricultural advisor, indicated that the interaction of percolation with soil type and water salinity was missing. Specifically, he said:

> 'I understand that percolation depends on the type of soil, but I miss a graph which would tell me if the salinity influences the irrigation water as salinity is a crucial factor to deal with in my plot, given the poor irrigation water quality.'

During the pre-trial run interviews, the participating farmers and agricultural advisors did not recommend these sets of information to be included. However, they are now aware that the information is important and will influence their uptake of the bulletin.

Table III. Pooled usefulness ratings pre- and post-trial run

	Pre-trial run				Post-trial run			
Item	*n*	Mean	SD	Med	n	Mean	SD	Med
SUMMARY	8				8			
COMPARISON	8	6.1	0.64	6	8	5.1	0.99	5
LWEEK	8	5.5	0.76	6	8	5.4	0.74	5.5
FORECAST	8	6.3	1.04	7	8	4.6	1.69	4
OPTIONS	8	5.1	1.13	5.5	8	3.9	1.46	3.5
SOILWATER	8	5.6	1.19	6	8	4	1.07	4
PERCOLATION	8				8			

SUMMARY = Summary table of monthly irrigation levels, *COMPARISON* = Graphical comparison of monthly irrigated amounts and crop water requirements, *LWEEK* = Graphical representation of irrigated amounts versus crop water requirements of last week, *FORECAST* = Daily weather and evapotranspiration forecasts, *OPTIONS* = Table of irrigation scheduling options, *SOILWATER* = The impact of different irrigation scheduling options (dose and frequency) on minimum available soil water, *PERCOLATION* = The impact of different irrigation scheduling options (dose and frequency) on the mean relative percolation.

Inaccessibility The post-trial run survey revealed that the majority of participants did not find the information in the bulletin difficult to understand. Specifically, none of the farmers and agricultural advisors had any difficulty understanding information relating *SUMMARY*, *COMPARISON* and *LWEEK*. However, two participants had difficulty understanding information relating to *OPTIONS* and one participant had difficulty understanding *SOILWATER* and *PERCOLATION*. One participant, an agricultural advisor, revealed that he found *FORECAST* ambiguous, and expressed his doubts on ET_0, ET_c and rainfall in the following way:

> 'I don't understand the relationship between ET_0 and ET_c. For example, for the 21st and 23rd of March you have to irrigate almost the same (ET_c are almost the same) but on the 21st it rained a lot (22 mm) and on the 23rd nothing. Why?'

To this participant, the logic behind the recommended irrigation levels appeared inconsistent with the weather.

As for *PERCOLATION*, two participants confessed that they struggled with interpreting the graphics (i.e. the dots and colour scheme gradients in relation to the *x*- and *y*-axis labels) in the bulletin as well as the interaction between the minimal fraction of total available water and the relative percolation.

Lack of confidence One participant, a farmer, indicated that his irrigation planning has changed since receiving the bulletin, despite his reservations about the uncertainties associated with changing their schedules.

1. 'I'm scared of using less irrigation water because I don't know what will happen. I have never worked with low levels of water, but with the bulletin I have been able to make some changes to my irrigation schedules.'
2. 'It [the bulletin] asks me to lower my irrigation use to 60% of what I use today. I don't know if this will work for my crops, but I have already lowered 90 $m^3 ha^{-1}$ in a week, when I normally use 300 $m^3 ha^{-1}$.'

One participant, an agricultural advisor, provided positive feedback to the trial run as follows:

> 'Most of the bulletin is very interesting…. Congratulations with the effort, it would be interesting if this information does not get lost, and it should get to other farmers and technicians.'

The statement above suggests that this particular person found the information valuable and would like to see others adopt the bulletin as well.

Institutional and political barriers When it comes to paying for the information, both farmers and agricultural advisors were less supportive of the idea. The average rating for farmers was 4 (min =1, max =7) and for agricultural advisors was 2.8 (min =2, max =4). However, the ratings were not statistically significant between the two profiles because the farmers' responses had a large variance. During the pre-trial run interview, one participant mentioned the economic crisis as a barrier for his ability to pay.

DISCUSSION

The weekly irrigation advisory bulletin was designed to support farmers in their weekly decisions on irrigation planning by combining different pieces of up-to-date information into a single document. Farmers were asked to assess the level of usefulness of the various pieces of information in the bulletin so as to inform developers how it can be improved.

Farmers and agricultural advisors show very little significant difference in their usefulness ratings of the information provided in the bulletin and their level of confidence in it as a decision-making tool (i.e. no substantial evidence of profile heterogeneity). That is because both groups of individuals are heavily involved in or responsible for irrigation decision making on the farm. In addition, these two groups of individuals display similar attitudes because they are both early adopters of technology. Pooled responses (i.e. of farmers and agricultural advisors) were found to be different before and after the trial run. Before the trial run, participants rated the usefulness rating of *FORECAST* to be one of the highest, indicating their anticipation that they will be using this information a lot. However, after trialling the bulletin, participants changed their rating and no longer rated the usefulness of *FORECAST* highly. This may reflect that fact that farmers and agricultural advisors were more confident about outputs in the past than predictions into the future. Additionally, the general drop in ratings of *COMPARISON*, *FORECAST* and *SOILWATER* potentially reflects the end-users' dissatisfaction with the bulletin to deliver these sets of information after actual use. This supports our argument that end-user feedback post-implementation of the tool should not be ignored because end-users often discover their true needs and preferences after actual use.

In order to avoid the pitfalls that would lead to non-adoption of the bulletin or any other types of decision support tools for this matter, we discuss ways in which the issues identified by the survey participants could be overcome. This can significantly improve the functionality of the design in relation to the objectives (e.g. Tessmer, 1994; Vanclay and Lawrence, 1994; Walker, 2002) and lead to long-term adoption of the tool.

Overcoming irrelevance

How relevant is the tool to real decision-making processes? From a user-interface perspective, it was observed that the most useful diagrams were those in which actual and recommended irrigation levels were compared, while the diagrams reporting the recommended forecast irrigation levels (Figure 3) were found less useful. The actual versus recommended water use diagram (Figure 5) allows farmers and agricultural advisors to compare and validate their actual performance against the experts' recommendations. Hence, the farmers and agricultural advisors are utilizing this information to reflect 'backwards' and evaluate how they performed against the expert benchmark. To produce these diagrams, the farmers and agricultural advisors would have to report their irrigation level back to the research team on a weekly basis. As such, the level of interest may also stem from their personal involvement in the data collection process. In any case, this process keeps end-users engaged and encourages ongoing use of the tool. Vice versa, end-user engagement has been found to improve the quality and relevance of the tool, leading to its successful uptake (see e.g. Hwang and Thorn, 1999).

Overcoming inflexibility

How well does the tool address the range of information that is accurate, useful and timely for the end-user? From a technical perspective, several participants indicated that they were reluctant to follow the recommended irrigation level because the estimation did not account for salinity and water quality. Their concerns are valid as water quality in this region is highly variable, depending on rainfall, surface water availability and the proportion of groundwater that has been mixed with surface water to increase irrigation water availability.

This concern can be remedied through the modification of the irrigation scheduling options (*OPTIONS*). Multiplicative factors given for irrigation doses (for three different levels of salinity found in the irrigation district) will allow farmers and agricultural advisors to adjust the bulletin recommendations based on the water quality level in each of their plots. However, it will be more accurate to also simulate water quality in the SWAP model, to better account for the effects that could have different irrigation frequencies and doses.

Additionally, the design of the bulletin could better demonstrate how small variations in soil, crop characteristics and climatic conditions affect the variables and output presented. This would allow the end-user to fine-tune the information provided to their local situation. Also, water stress sensitivity for crop variety can be included to adjust the recommended irrigation level in the bulletin and give more information for applying deficit irrigation. With these factors taken into account, farmers can time when to be more aggressive with irrigation dosing cuts and when to be more generous with more precision.

Since the bulletin is sent out weekly, it can be easily disseminated via email or the regular mail service. Hence, participants can receive the information in a timely manner. Participants were also keen to access the information via the internet, as indicated by their average response of 5 (on a scale of 1–7) to the question as to whether they would try to access this information if it were available on the internet.

Overcoming inaccessibility

How easy is the tool to understand? Although the bulletin has overcome physical and technical accessibility because it is delivered directly to the farms, there is still the matter of conceptual inaccessibility that needs to be tackled. Despite being early adopters of irrigation technology, not all participants had a good grasp of scientific terms such as ET_0, ET_c and the difference between water content at field capacity and permanent wilting point. When the information presented is difficult to understand and counter-intuitive, despite being technically correct, end-users can become sceptical and choose conservatively not to follow the recommendations because they do not fully understand the rationale behind the numbers.

We found that the use of graphics, varying colour gradients, in combination with short descriptions to explain scientific terms (e.g. statements such as 'reference water demand' and 'maximum crop water demand' to complement ET_0 and ET_c, respectively) improved understanding significantly. The information appeared less intimidating and more intuitive to the end-users. This is consistent with other studies that have found that well-designed graphics and visual cues reduced decision-making task complexities and time taken to perform a task (Benbasat *et al.*, 1986; Crossland *et al.*, 1995). In order to guide the type of graphics to choose, a comparative research, via the means of an experimental design, can be used to test how information is interpreted by the end-users based on the choice of graphics.

Overcoming lack of confidence/trust

Are end-users confident in the tool? In order for the adoption of the bulletin to spread through to other farmers in the Segura River Basin, it is important to receive positive feedback from early adopters who would be spreading word of its practical use. Despite some doubts about the reliability of the recommended irrigation schedule, one of the participants chose to adjust their irrigation schedules based on the information provided by the bulletin. This suggests a certain degree of trust and confidence the participants had in the science (i.e. the knowledge of the researchers and the integrity of the research findings) behind the information, or the institution that provided the information. A study by Parker and Sinclair (2001) also found that user-centred DSS designs lead to end-user trust in the design team of crop production. This trust can be increased when researchers take into account farmers' knowledge, provide information that is required in both content and form, and present the information using less technical terms and more descriptive labelling.

Overcoming institutional and political barriers

Are external factors hindering the adoption process? Although the participants were very positive towards the bulletin, there are other barriers that could possibly hinder its adoption. One of these is the ability and willingness to pay for the information. This is not surprising, as one of the farmers interviewed mentioned the current economic crisis in Europe and having limited funding to spend on this type of investment at the time of the survey. It is known that context plays an important role in end-user attitude towards the decision support tool. Eierman *et al.* (1995) argued the importance of the 'environment construct' of a DSS in that major forces external to the DSS have the potential to influence the attitude and behaviour of end-users. In the context of this study, the economic environment played a role in influencing farmers' ability and willingness to pay for the tool.

Assuming they are able to pay for the bulletin, farmers and agricultural advisors may increase their level of willingness to pay if it is more tailored to their specific situations and helps reduce water use while maintaining the same level of productivity. If ability to pay is an issue, irrigation institutions, such as the Campo de Cartagena Irrigation Community, may be willing to subsidize farmers to assist with such costs. This can be evaluated in further studies using non-market techniques such as the contingent valuation method or choice experiments, where income (i.e. ability to pay) is explicitly captured.

The success of the programme could also be significantly increased with government subsidies to finance ongoing research, tool development and dissemination of the bulletin. Otherwise, adoption may not occur due to financial constraints at the individual level.

CONCLUSION

In recent years, several authors have stressed the importance of end-user participation in the development of decision support tools for farmers (see e.g. Herrmann *et al.*, 2011; Thorburn *et al.*, 2011). They argued that a stakeholder consultative process is not sufficient to ensure that the tool would meet end-user requirements as the developers will always give their own interpretation to some extent.

Findings from this study support these claims and highlight the need to involve end-users' feedback post-implementation in the design of decision support tools. End-user participation can be problematic when there is a discrepancy between what end-users 'perceive' to be useful information and what information may 'actually' be useful in the field. This could lead to the design of a decision support tool that is irrelevant to decision making. This is neither the fault of the developer nor the end-user. It is simply due to unforeseeable needs that only come to light when the tool is put into practice. In the psychology discipline, conscious wants and desires have been found to often run counter to actual needs because of various dynamic and cultural influences (Ryan, 1995). Without post-implementation feedback from end-users, it is difficult to assess whether the needs identified in the design phase by the end-users were actually conscious wants rather than real needs. Consequently, the tool may be too irrelevant, inflexible and inaccessible, and barriers such as lack of trust and institutional and political barriers lead to non-adoption. Therefore, it is important that barriers to adoption are identified and addressed before the decision support tool is developed.

Although it is ideal to involve more farmers and agricultural advisors in the consultative process, time, budget and manpower constraints limit the ability to implement the bulletin trial run at a wider scale. The nature of the bulletin, being farm-specific, limits the amount of bulletins that can be produced and disseminated by the researchers, and as a result limit the number of farmers and agricultural advisors that could participate in the trial run. Therefore, caution should be exercised when generalizing the findings to all other farmers. However, the diffusion of technology normally starts with early adopters or innovators. Hence, the participation of innovative farmers and agricultural advisors in this study should be a good indicator of the general acceptance and uptake of the tool in the future by other types of farmers.

In the context of irrigation, we identified a number of critical factors that would have been overlooked in the design of the irrigation advisory tool if post-trial feedback of the tool was not considered. We also suggested how these factors, which act as barriers, could be overcome. Knowledge gained and shared from this experience is informative for other researchers who are in the process of developing an irrigation advisory tool to assist farmers with their irrigation decision making under severe drought conditions.

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