IPM Decisions

D5.4: Report on the incentives and barriers to uptake DSS by different end-user types

Grant agreement number: 817617

Start date of project: 01/06/2019 **End date of project:** 31/05/2024

Deliverable due date: 30/11/2023 **Date of delivery:** 30/11/2023

Classification: Public

Version History

Version number	Implemented by	Reason
1.0	Nikos Georgantzis	WP5 lead
2.0	Nikos Georgantzis	Edited following comments by the research team

List of Authors

Company	Author(s)	Contribution
ADAS	Mark Ramsden	Writing
BSB	Nikos Georgantzis	Coordination
BSB	Jotham Akaka	Data analysis; writing
BSB	Efi Vasileiou	Data Analysis Coordination
UJI Spain	Aurora Garcia Gallego	(J. Akaka's) Thesis Supervision, writing.

List of Reviewers

Company	Reviewer	Contribution
ADAS	Mark Ramsden	Review and formatting
ADAS	Neil Paveley	Review

Contents

Public Summary

The main drivers and barriers for the adoption of Decision Support Systems in pesticide management have been identified through analysis of potential user responses to a questionnaire administered during a series of workshops throughout Europe.

Executive Summary

During a series of workshops with (potential) users of Decision Support Systems (DSS) data was collected from questionnaires addressed to the participants and used to analyse barriers and drivers of end-users' adoption decisions. In this document we report the analysis of the resulting data set, aimed at identifying the behavioural, socioeconomic and crop-related features that can be used to understand the decision-making process underlying a (potential) DSS user's adoption decision. Based on the same dataset, Deliverable 5.3 has already provided insights on the user characteristics and the interplay between types of DSS and farm-specific needs which may facilitate or hinder the adoption of a DSS by the end user. Expanding that analysis, this deliverable proposes a structural model that captures the interdependence among drivers and barriers which lead a user to be willing to adopt a DSS (adoption model) and to pay (WTP model) for it.

Major user, product and farm-specific determinants have been identified suggesting that a complex process underlies the decision to adopt a DSS, as well as a farmer's willingness to pay for it. Younger farmers are more willing to adopt a DSS because they enjoy using new technologies. Other demographics play a lesser role, except for income, whose effect, however, is related to farm size. Trust in DSS outputs plays a modest role in determining the farmer's willingness to pay, although trust becomes the major psychological component, by internalising the farmer's tendency to trust colleagues and other people in general and it becomes the channel through which risk attitudes affect a farmer's willingness to pay.

The study pays special attention to the way in which risk attitudes are measured, proposing a two-dimensional description, including risk aversion and sensitivity to risk-return variations. A list of factors affecting DSS adoption and willingness to pay is provided in the discussion, showing the joint importance of individual, farm-specific and DSS-specific features, as well as the complexity of effects for which the researcher cannot rely on "expert" or "user" opinions alone.

1 Introduction

Invertebrate pests, pathogens and weeds (collectively 'pests') can reduce both the quantity and/or quality of crops and require continuous management. According to the EU's Sustainable Use Directive (SUD 2009/128/EC) and specifically the third principle of Integrated Pest Management (IPM), farmers should be supported through the use of forecasts, economic thresholds or other IPM Decision Support Systems (DSSs) (Barzman et al., 2015). Despite many IPM DSS being available across agricultural sectors, including some examples of well tested and implemented systems (Shtienberg, 2013), uptake by farmers and their advisers remains low. Uptake has been constrained by numerous factors, associated with either the technical development and availability of systems, or the way in which farmers and their advisors are engaged with during development and end product launch. The latter frequently results in DSS being either rejected by potential users, or the outputs of the system are not perceived as sufficiently trustworthy to influence pest management decisions. The work presented here investigates the socioeconomic and technological drivers of the uptake, trust in IPM DSS and willingness to pay (WTP) in Europe and discusses opportunities to apply these findings.

1.1 Some background on Decision Support Systems

Decision Support Systems provide farmers with reliable scientific data, promote innovation, and reduce wastage (Fountas et al., 2005; McCown et al., 2009; Thorburn et al., 2011). The agricultural sector faces the challenge of a growing global demand for food, while preserving biodiversity, combating climate change and ensuring that production is sustainable and economical (Aubert et al., 2012). The decisions associated with pest management can be among the most difficult that farmers and their advisors face during the growing season (Ramsden et al., 2017). Applying pesticides when the actual risk of pest damage is low rarely leads to acute repercussions but has chronic impacts on the long-term sustainability of crop production and the health of the surrounding ecosystem (Aktar et al., 2009). Conversely, farmers can experience substantial economic losses where pest infestations are left unchecked and go on to cause widespread crop damage (Oliveira et al., 2014). The main purpose of a DSS is to enable users to make more effective decisions. For the outputs to be trusted, DSSs must not only be reliable, but also clear in their limitations and assumptions (Rossi et al., 2014). Currently, the common types of IPM DSS used are tactical systems, supporting decisions on when to monitor crops for pest activity and when action may be required to prevent economic losses, such as monitoring systems, forecasting systems and thresholds (Damos, 2015). Monitoring systems report actual occurrences of given pests at a defined spatial scale. Pest forecasts are based on algorithms that model a given pest's ecology from climatic and/or agronomic inputs to predict the likelihood of infestation and/or the risk to the crop (de la Fuente et al., 2018). Together these provide farmers and their advisers with an insight into the current and future risk of infestation in their region, supporting decisions on whether further crop monitoring and/or management actions are required (Zhiembayev et al., 2020). Economic thresholds are based on the potential for a given pest to cause economic damage to the crop and are a final assessment of the need to act (Ramsden et al.,

2017). A majority of IPM DSS require user inputs such as field location, soil type and structure, climate data, and agronomic details such as sowing date and crop variety. Based on these data the DSSs algorithms are run, and the system outputs potential strategies (decision aids/treatments) that the farmer can choose from (Seem & Russo, 1984). Outputs range from a relative assessment of the risk of infestation and/or economic damage, to specific recommendations for treatment, such as application of a given pesticide or bioprotectant.

Over the last three decades, there is a growing concern that even though agricultural DSSs are available for farmers, they are neither fully utilised nor appropriate for the complexity of the daily decisions farmers face (Eastwood et al., 2012; Van Meensel et al., 2012a). In part, this may be due to a lack of clear evidence that the use of DSS leads to improved economic returns, and there is increasing effort to address this. In weed management, for example, some DSSs determine the density of weeds at which a control treatment will provide an economic return (Higley & Pedigo, 1996). Economic thresholds such as this are highly valued by farmers and have been developed for many pests (Auld & Tisdell, 1987; Neeser et al., 2004), however they can be difficult to develop and establish in farming practice (Ramsden et al., 2017).

From inception, most DSSs are primarily designed to handle farm and crop production data. The weakness of this approach is that the role of the farmer, and other auxiliary factors, are minimised or left out completely. User characteristics are, however, key factors influencing the adoption and application of DSS (Aubert et al., 2012). The data-focused nature of DSS is an understandable by-product of developers' efforts to optimise their DSS to work with certain types of pests and crops, making them specific and detailed. In contrast, farmers prefer to have a broader view, reflecting the polyvalent spectrum of day-to-day decisions they face (Rossi et al., 2014). Van Meensel et al., (2012b) conclude that some DSS are overwhelmingly complex, the terminology and functions are not only unsuitable but often irrelevant to the final user. Other DSS may be simple, but the Graphical User Interface (GUI) is too complex, either by poor design, or due to the high frequency of changes made by developers to optimise their product. Therefore, if farmers interact with a few complex systems, it can lead to a community level perception of all DSS being too complicated to be of value. In addition, many DSSs lack a proven track record of their effectiveness in farming. This is in part explained by the agricultural DSS development cycle, in which systems are often the culmination of a short term (3-5 year) research project(s). The main activities in such projects involve coding and GUI design, instead of demonstrating the economic and environmental benefits the system offers. A focus on algorithm development, and optimal GUI design, with omission of the influence of user behaviours has led to a dismal adoption and general lack of trust in agricultural DSS to date among farmers.

Decision making and technological adoption theories provide useful insights into the low rates of adoption of agricultural DSSs. The theories of adoption of new farming practices have been extensively documented, identifying the factors influencing the adoption of farming technology (Feder & Umali, 1993; Kuehne et al., 2017). Conventionally, decision-making

process theories identify three main factors: farmer, technological and institutional characteristics (Meijer et al., 2015). A review by Kumar et al. (Kumar et al., 2018) identified the source of information, technological features, economic factors, farm characteristics, institutional and sociodemographic factors significantly influencing the adoption of farming technologies.

In this study, farmer and farm-related characteristics collected during workshops across Europe were used to assess the factors influencing the uptake and trust in IPM DSS. As suggested by Davis (1989) in the Technology Acceptance Model, technology acceptance and usage are determined by the perceived usefulness and the perceived ease of use. Perceived usefulness is the utility gained from improving one's work performance due to the use of a certain technology, whereas perceived ease of use is related to the effort required to use a certain technology (McDonald et al., 2016).

2 Data collection and modelling

A questionnaire survey was administered to 149 farmers from 11 European countries (Table 1), eliciting personal, farm and farm equipment characteristics that influence the adoption and trust in DSS. The survey was designed in consultation with a team of experts working closely with the IPM Decisions Network.

Table 1: Number of total responses, per country and workshop

Country	*Main questionnaire (2020)*	*Second round (validation) questionnaire (2021)*
France	6	0
Greece	22	8
Lithuania	9	21
Denmark	4	4
Italy	37	29
Slovenia	14	3
United Kingdom	24	11
Sweden	11	9
Finland	9	10
Germany	9	9
Holland	4	5
Total	**149**	**109**

The questionnaire was completed by farmers during national workshops (Marinko et al., 2023). The workshops were held face-to-face between December 2019 and March 2020. A further round of national workshops was carried out online between January and March 2021, where a second questionnaire was administered to farmers. This was used to assess the perceived relative importance of the variables from the analysis of the first questionnaire. Each question of this complementary questionnaire focused on the variables used as

explanatory variables in the econometric model derived from the first questionnaire. Each question in the second questionnaire had three options to choose from: “not important at all,” “important to some extent,” and “very important”.

2.1 Variables and descriptive statistics

In line with the General Data Privacy Policy, respondents were free to exclude any information they did not wish to share but were encouraged to provide as much information as possible. Consequently, there are several missing observations for some variables resulting in an uneven dataset. A summary of the responses to questions eliciting the characteristics of the respondents and their farms is provided in Table 2. The characteristics of the farmers in Greece, Italy, the United Kingdom and Slovenia are summarised in Table 3. An overview of all the variables created from the questionnaire is provided in Table 4 (see Appendix A).

Table 2: Percentage of answers related to the main variables (N=149)

Age			**Type of farm**	
18 to 25	7.4%		*Conventional*	40.5%
25 to 35	25.5%		*Integrated*	29.4%
35 to 50	27.5%		*Organic*	9.2%
50 to 60	29.5%		*Biodynamic*	0.6%
60 or more	10.1%		*Not indicated*	20.2%
Highest degree attained			**Farm size**	
Vocational	40.3%		*Under 5HA*	10.1%
Bachelor	27.5%		*5 to 10 HA*	2.7%
Masters	17.4%		*10 to 30 HA*	18.1%
PhD	4.7%		*30 to 60 HA*	14.1%
Others	6.7%		*Over 60 HA*	54.4%
Average income (euros per year)			**Access to speed internet**	
Under 20K	21.5%		*No*	10.1%
20 to 35K	20.8%		*In the office only*	38.6%
35 to 50K	20.1%		*Also in the fields*	52.3%
50 to 75K	12.1%			
Over 75K	22.1%			
Gender			**Already tried using a DSS**	
Male	80.5%		*Yes*	60.4%
Female	18.8%		*No*	24.2%
Not indicated	0.7%		*Not indicated*	15.4%

2.2 Data analysis and modelling

Questionnaire responses were analysed to identify and measure the relationship between WTP and DSS adoption with other explanatory variables. We use partial least squares structural equation models (PLS-SEM) that are robust even with small samples. The answers to the questionnaires were analysed in detail to estimate a structural model, identifying linkages between the use of DSS, trust in the guidance of DSS and other explanatory factors. The analysis was conducted using specialised statistical software (Stata and SmartPLS) taking care of the relatively small sample, the complexity of possible relations among explanatory variables and considering the binary nature of the DSS adoption variable. Regarding the variables used in the models, particular attention has been paid to multicollinearity issues. While there is no specific test for multicollinearity, special attention has been paid to several model quality signals such as the model stability, the variance inflation factors (VIF) and the correlation of the estimated coefficients. Specifically, two partial least square structural equation models are estimated to identify factors influencing 1) the decision to adopt DSS (DSS adoption model) and 2) the willingness to pay for DSS (WTP model).

Additionally, the respondents' attitudes towards risk were elicited through the lottery panel task (Sabater-Grande & Georgantzis, 2002), whose interface is presented in question 42 of the questionnaire (Appendix B). The task is based on four panels of lotteries which are designed to compensate a lower probability of winning with a higher expected payoff. Panel 1 offers a lower compensation to riskier choices than Panel 2, Panel 3 and so on. Thus, the test exposes participants to a choice of the preferred lottery, thus eliciting 1) the respondent's propensity to take riskier choices and 2) the respondent's tendency to alter his or her decisions according to changes in the risk-return parameter. We have identified two components which describe a decision-maker's risk attitude. The first one is the well-known risk aversion component, related to a person's aversion towards riskier choices, even when these are associated with higher monetary gains. The second factor is a person's sensitivity to changes in the risk-return relationship. Factor analysis (Appendix C) has revealed that the first component, risk aversion, can be approximated by a relatively balanced positive loading of each respondent's choices in the four panels, while the second component involves the difference of choices between panel 4 and 1 and between panel 3 and 2 (with the former difference being loaded double as much as the latter). This task offers a more complete description of risk attitudes than single-task unidimensional risk elicitation procedures, beyond aversion to risk, because it also accounts for differences of actions across different risk-taking contexts. Furthermore, our analysis below shows that both factors are necessary for the WTP model to perform reasonably well, considering the two constructs account for more than 80% of the total variance.

2.2.1 Factors influencing adoption of decision support systems

Figure 1 presents the interconnections among variables which can explain the decision process leading to the adoption of a DSS. Like in previous approaches reported in D5.3 and in [30], farm size is positively related to the adoption of a DSS. Its effect is enhanced by its two associated factors, income and arable crops. A unique crop managed by a farmer has also a positive impact. Both factors' impact on DSS adoption is mediated by male gender: positively

for farm size and negatively for unique crop. This is the only gender effect captured by our analysis. A young age is the other demographic trait that enhances the probability of adopting a DSS, and its effect emerges since younger users enjoy using new technology.

Among all positively perceived characteristics of a DSS, the only ones that matter in DSS adoption are the perception that the DSS is efficient and that it is easy to use. Finally, the only external intervention that was found to significantly contribute to a farmer's DSS adoption decision is exposure to demonstration sessions.

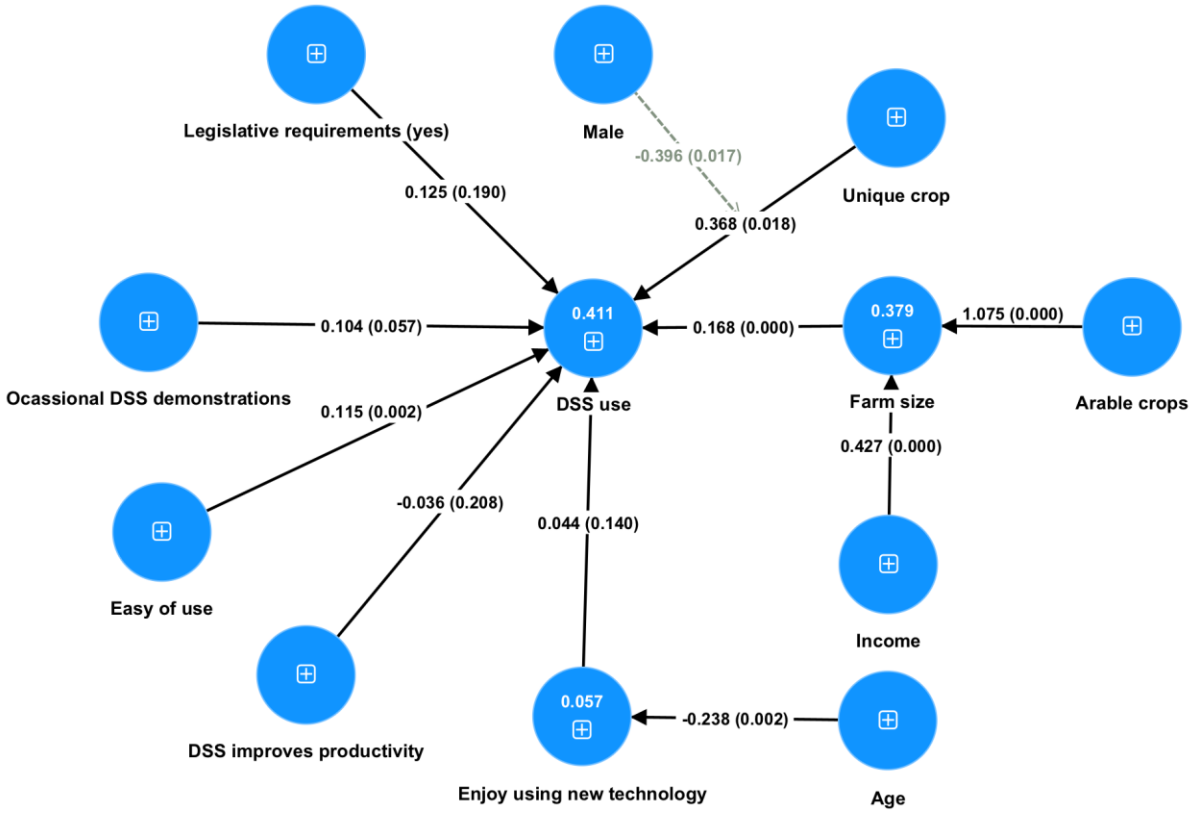

Figure 1: DSS adoption decision model (SEM estimated with SMART PLS). Numbers in circles are model coefficients, numbers on the arrows are path coefficients and numbers in parentheses are p-values.

2.2.2 Factors influencing willingness to pay for decision support systems

Figure 2 presents the results of a second model, which concerns the monetary valuation of a DSS, measured by the user's willingness to pay for it. The model has been estimated as an independent model from the first one, because the decision to use a DSS is almost a necessary condition for the user's WTP for it. Overall, the mechanism behind a significant monetary valuation of a DSS by a potential user is a rather complex one. Experience using a DSS is found to be significantly associated with the willingness to pay for it. The effect is further enhanced by the user's perception that the DSS is efficient, which is positively associated with the use of the same DSS as one's advisor. Again, a larger farm and a specialization in arable crop farming significantly contribute to the economic value of the DSS as reflected by the user's

WTP for it. The effect of a larger farm is further enhanced, when farmers are satisfied with their current level of production. Therefore, stability in a farmer's plans make the farm size effect stronger. Farm size is also positively associated with income, and this is the way in which income is also positively related to the WTP for a DSS. Farmers who declare to be very sensitive to the price of a DSS are less willing to pay for it. On the lefthand side of the graph, we find variables which affect the user's trust in DSS. This is driven mostly by psychological traits, like the farmer's tendency to trust in others (composed by trust in friends' and colleagues' advice) and the farmer's risk attitude. In this risk attitude-related effect, we found that the sensitivity to variations in risk-return trade-offs plays a more significant role than risk aversion. This sensitivity to risk-returns variable may even be capturing the farmers' better ability to calculate the risks, thus reacting more rationally to the challenges of their environment. Finally, farmers' intrinsic willingness to try new products plays a significant role in their trust in a DSS, while marketing sessions have no statistically significant effect, but if there were any effect the sign would be negative. Surprisingly, the farmer's trust in DSS seems to have only a weak positive effect on their willingness to pay for a DSS.

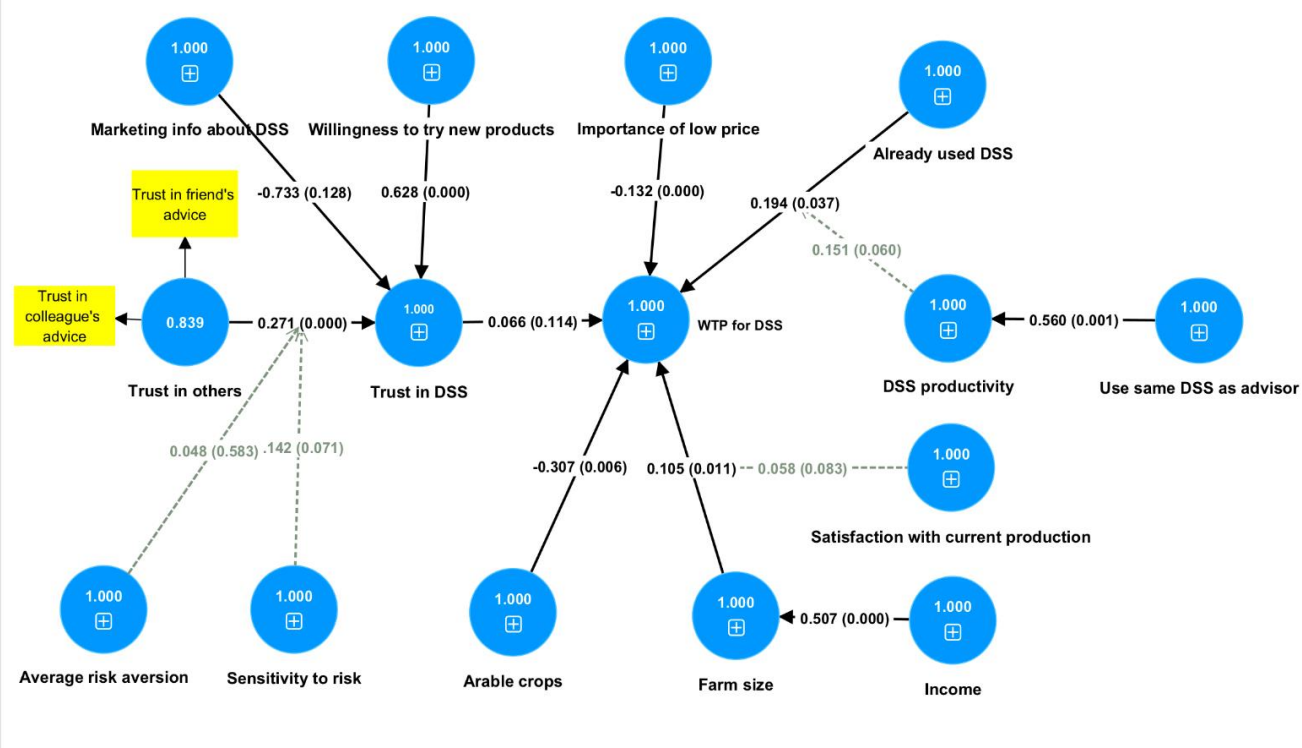

Figure 2: Willingness to pay for DSS model (SEM estimated with SMART PLS). Numbers in circles are model coefficients, numbers on the arrows are path coefficients and numbers in parentheses are p-values.

3 Discussion

The results from the two structural models presented have several common elements with those reported following the econometric analysis and data mining techniques in D5.2 and [30]. However, the structural equation modelling techniques adopted here uncover a more complex process underlying a potential user's decision to adopt a DSS and the willingness to pay for it. Furthermore, the process identified consists of a structure of interdependent determinant factors which are robust to country differences, because most factors concern either the features of the farm, or the farmer's perceptions and attitudes. To make our findings easier to follow and reference for policy and decision making, we present here the list of drivers and barriers discussed together with suggested lines of action to mitigate barriers and facilitate the drivers to adoption. Definitions of the variables are provided Appendix A.

Farm size (and satisfaction with current production for WTP)

- Farm size is a significant determinant factor of both DSS adoption and a farmer's willingness to pay for a DSS. Furthermore, regarding the effect of farm size on WTP, we found that such an effect is stronger for farmers who are satisfied with their current level of production.
- Potential users associated with larger farms are more likely to adopt DSS, and more willing pay for DSS, than those associated with relatively smaller farms.
- When engaging with larger farms, promotion activities should focus on providing evidence of benefits to avoiding unnecessary applications while maintaining levels of production.
- When engaging with smaller farms, promotion activities should focus on the benefit of free access to DSS, and opportunities to reduce input costs/increase production through lower input/targeted inputs according to need.

Arable Crops

- Like farm size, it is a significant driver of a farmer's willingness to pay for a DSS, while it interacts positively with farm size (arable crops related to larger farms) to enhance DSS adoption.
- Farmers growing arable crops are more likely to be willing to pay for DSS, especially when adopted on larger farms.
- When engaging with large arable farms, promotion activities should focus on facilitating engagement between farmers to help i) promote farmers advocating DSS use already, and ii) improve support in interpretation and confidence in outputs.
- When engaging with non-arable farms, promotion activities should focus on the benefits of free access, and how DSS can be developed, evaluated, and demonstrated – ideally using existing examples, or connecting users and developers.

Unique crop

- Association with a unique crop is positively related with DSS adoption, although the effect is weaker for male farmers.
- Farmers focusing on unique crops are more likely to use DSS, more so if the user is female.
- When engaging with farmers growing unique crops, promotion activities should focus on identifying the specific crop/pests of interest and connecting them directly with appropriate systems and/or developers to access/test/create appropriate DSS.

Already used DSS

- Current use of DSS increases the probability that a farmer is willing to pay for a DSS and this effect is stronger under the perception of a DSS as efficient and when farmers use the same DSS as their advisors.
- When engaging with farmers already using DSS, promotion activities should focus on presenting up to date evidence of benefits and encouraging farmers to discuss each DSS with their advisor.

Income

- Income is positively associated with both DSS adoption and WTP for a DSS, but the effect is related to that of farm size.
- As it is not appropriate to confirm income levels of farmers during engagement activities, this should effectively be covered through other approaches, especially those targeting larger farms.

Gender

- Gender has a discrete role in the adoption model alone. Being male implies a weaker "unique crop effect".
- Thus, the impact of gender on DSS adoption and WTP is not sufficiently influential to justify approaching engagement of farmers of different genders differently.

Age

- Younger farmers are more likely to adopt DSS because they enjoy using new technologies.
- When engaging with younger farmers, promotion activities should focus on the technical aspects of using the systems through the platform; ability to adjust parameters, compare models, review data etc.
- When engaging with older farmers, promotion should focus on ease of use to access risk assessment for a range of crop/pest interactions.
- When engaging with a mixed age group, focus should be on the ease of use, and the ability to only look at DSS components and functions in more detail if needed.

Individual attitudes towards risk and trust

- Trust has a weak positive effect on the willingness to pay for a DSS. However, the factors leading a farmer to trust a DSS relate mostly to underlying psychological processes like risk attitudes, a farmer's generic willingness to try new products and a farmer's tendency to trust in friends' and colleagues' advice. Trust can be weakly (and negatively) affected by DSS advertising.
- Risk attitudes matter for willingness to pay, but the mechanism is more complex than through the usual risk aversion channel. Both risk aversion and sensitivity to risk-return variations are needed to describe risk attitudes, which then determine trust in DSS.
- When engaging with farmers, the concept of risk needs to be made clear at the start of communications, outlining what risk forecasts are and how they should be interpreted within the context of each individual farm and/or field. It should also be made clear how DSS outputs can be reviewed during/after a season and provide opportunity for discussion and review. Examples of DSS results, and routes to look at historic data should be made available. Each farmer should be encouraged and supported to i) understand the risks and how they consider

them in making decisions, and ii) understand how they should consult DSS to improve decision making on their farm.

Willingness to use new products

- Willingness to use new products is a major factor in both DSS adoption and WTP for DSS. In the adoption model, it becomes the explanation why younger farmers are more likely to use a DSS.
- When engaging with farmers, this can be an opening to communications, 'How willing are you to adopt new products?', and can be asked again at the end 'How willing are you now to adopting a new DSS?'.

Perceived DSS productivity

- Farmers perceived influence of DSS on productivity has a direct and significant impact on DSS adoption, while it impacts willingness to pay by moderating the effect of already having used a DSS. In that case, the perception that a DSS is productive is higher when the farmers use the same DSS as their advisors.
- When engaging with farmers not already using DSS, promotion activities should focus on presenting evidence of the benefits of DSS consultation to productivity (as well as other benefits).
- When engaging with farmers already using DSS, promotion activities should still present benefits of DSS on productivity, but also the benefits of consultation in facilitating discussion with advisors to fine tune management decisions.

DSS perceived as "easy to use"

- Ease of use has a strong direct effect on the DSS adoption decision.
- When engaging with farmers, the simplicity of the platform should be emphasized, and clearly demonstrated.

Importance of low price

- Low price has a strong negative effect on a farmer's WTP for a DSS.
- Thus, farmers willing to pay for DSS are not influenced by a low value attributed to the DSS. They are looking to pay for a system that works, not a cheap system.

Legislative requirements

- Legislative requirements do not seem to significantly affect adoption decision or the farmer's WTP for a DSS.
- At present, there is no legislative requirement for DSS adoption in Europe. Were this to change, the influence of this may be relevant.
- When engaging with farmers, reference to legislative requirements should be minimize unless there are highly relevant national/international requirements.

DSS Demonstrations

- Demonstrations positively influence DSS adoption, but not a farmer's willingness to pay for a DSS.
- When engaging with farmers, this should either be done within the context of a demonstration event, or a relevant case study should be presented either using existing case studies or using the platforms 'comparison' dashboard.

Marketing

- Exposure to DSS marketing has a weakly negative effect on trust in DSS.
- When engaging with farmers, generic messages must be avoided and impacts should be tailored to the region and group. Where resources are shared, these should be explicit in messages to avoid being seen as marketing.

3.1 External validity: A methodological reflection

In the second round of workshops, a short questionnaire was distributed among the participants, asking them to express their opinion on the importance of some of the factors we were analysing as candidate explanatory factors for DSS adoption. Table 3 presents the results of this exercise which can serve us to contrast our findings with stakeholders' views of our findings. On average, farmers reported that education was the most important factor (mean = 2.33), and that gender was not important at all (mean = 1.17) in DSS adoption.

Table 3: Questions to farmers and their expectations on the role of each potential explanatory factor of the probability to use a DSS

Question	Mean	Mode
Is the **price of DSS** important in adopting DSS among farmers?	2.5810	Very important
Is **the farmer's exposure to demonstrations** on how to use DSS important in adopting DSS?	2.6650	Very important
Is the **farmer's IT training** an important factor in adopting DSS among farmers?	2.5720	Very important
Is the farmer's access to **high-speed internet** important in adopting DSS among farmers?	2.4850	Very important
Is the **size of the farm** an important factor in adopting DSS among farmers?	2.0840	Important to some extent
Is the **farmer's income** an important factor in adopting DSS among farmers?	2.0450	Important to some extent
Are **legislative requirements** an important factor in adopting DSS among farmers?	2.2900	Important to some extent
Is **education** an important factor in adopting DSS among farmers?	2.3290	Important to some extent
Is the farmer's **age** important in adopting DSS?	2.1500	Important to some extent
Is the **farmer's exposure to advertisements** important in adopting DSS?	2.1800	Important to some extent
Is **gender** an important factor in adopting DSS among farmers?	1.1680	Not important at all

Scale: 1= "Not important at all"; 2= "Important to some extent"; 3= "Very important''.

With respect to the characteristics of the farm (size and internet), a relative majority of farmers answered that the availability of high-speed internet in the farm was very important and that the size of the farm was only important to some extent. Of the DSS characteristics, price and exposure to the demonstration were expected to be very important, while exposure to marketing was important to some extent. Beyond any effort to validate our results reported here with the opinions of farmers, this exercise clarifies how simple questions or speculative discussions about perceived importance of a factor cannot capture the complexity of the relations among the causes and the effects of behavioural patterns in any decision-making domain.

4 Conclusion

As the world gears itself to optimise food production and minimise the negative impacts of agriculture on the environment, individual decisions can have negative or positive impacts on productivity with minimised negative environmental impact (Van Meensel et al., 2012b). The onerous task of integrating farming data into daily farming routines falls to farmers and their advisers. The complexity and time-consuming nature of collecting and analysing farm data can be partially alleviated by computerised systems. Various decision support tools are available to support farmers and their advisers collect, organise, analyse and integrate farming/crop data to daily farming practices by using farm data and algorithms that report practical outputs against a specific set of criteria. They can support both individuals and groups in making optimal decisions when faced with structured or semi-structured problems. They also offer real-time support and assist in formulating long term strategies through decision training (Alenljung, 2008). To achieve greater uptake and implementation of IPM DSS, several key aspects need addressing. This study was designed to identify potential avenues leading to higher adoption rates and to explore the determinants of a farmer's willingness to pay for a DSS as a measure of the product's economic value.

Our results show that the size of the farm and type of crop (arable) have a positive and significant effect on the likelihood of adopting a DSS and the willingness to pay for it. Surprisingly, trust in DSS only weakly impacts on a farmer's willingness to pay for a DSS. Young farmers are a definite target group for the promotion of DSS use, as they are more likely to be open to new products in general. On the contrary, gender is not responsible for any significant differences and income is important in both adoption and willingness to pay, but the effect is due to farm size. Valuable properties of a DSS for both adoption and willingness to pay are to be perceived as efficient and easy to use. External campaigns in favour of DSS promotion should be based more on demonstrations, rather than marketing.

5 Appendix

Appendix A: Variables

Table 4: Variable description

Variable	Description
Age	Ordinal variable for respondent age group
Already used DSS	Dummy variable that takes a value of 1 if respondent has previous DSS experience
Arable crops	Dummy variable that takes a value of 1 if arable crops is the main farm output and 0 if otherwise
Average risk aversion	First factor scores obtained from the four panels in the SGG panel lottery task
DSS productivity	Ordinal variable for respondent belief that DSS can improve their productivity and efficiency
DSS use	Dummy variable that takes a value of 1 if respondent uses DSS regularly and 0 if otherwise
Ease of use	Ordinal variable for ease of use as an important DSS characteristic
Enjoy using new technology	Ordinal variable for respondent level of enjoyment in the use of new technology
Farm size	Ordinal variable corresponding to respondent farm size
Importance of low price	Ordinal variable for low price as an important DSS characteristic
Income	Ordinal variable corresponding to respondents proceeds from agriculture
Legislative requirements (yes)	Dummy variable that takes a value of 1 if respondent must comply with market regulations and 0 if otherwise
Male	Dummy variable that takes a value of 1 if respondent is male and 0 if female
Marketing info about DSS	Dummy variable that takes a value of 1 if the respondent has subscribed to receive marketing information and 0 if otherwise
Occasional DSS demonstrations	Dummy variable that takes a value of 1 if the respondent follows DSS demonstrations occasionally by invitation and zero if otherwise
Satisfaction with current production	Ordinal variable for respondent satisfaction with current production levels
Sensitivity to risk	Second factor scores obtained from the four panels in the SGG panel lottery task
Trust in colleague's advice	Ordinal variable for respondent trust in the advice of a colleague
Trust in DSS	Ordinal variable for respondent trust in the guidance of DSS
Trust in friend's advice	Ordinal variable for respondent trust in the advice of a friend
Trust in others	Latent variable obtained from trust in colleague's and friend's advice
Unique crop	Dummy variable with a value of 1 if the respondent only grows one crop type in their farm
Use same DSS as advisor	Dummy variable that takes a value of 1 if respondent uses the same DSS as advisor
Willingness to try new products	Dummy variable with a value of 1 if the respondent is willing to try new products
WTP for DSS	Dummy variable with a value of 1 if the respondent is willing to pay to use DSS

Appendix B: Questionnaire

Questionnaire n°1 (Potential) users

Dear participant,

This survey will help us know your views on Decision Support Systems designed to guide farmers towards a better pesticide management. To proceed with the survey please read carefully the following sentences and tick the relevant boxes as appropriate.

☐ I confirm that I have read and understood the terms and conditions for participating in the study.
☐ I understand that my participation is voluntary and I am free to withdraw at any time, without giving a reason and with no foreseeable consequences.
☐ I agree to take part in this study.
☐ I agree that the data gathered in this study may be stored (after being anonymized) in a secure storage facility and will be destroyed five years after the study ends.

1. In which country are you based?

2. Which is your age group?

☐ 18 to 25

☐ 25 to 34

☐ 36 to 49

☐ 49 to 60

☐ 60 or more

3. What is your gender?

☐ Male

☐ Female

4. **What is the highest degree you have attained?**

- ☐ Vocational qualification
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ PhD
- ☐ Others (please specify)

5. **Your farm is:**

- ☐ Less than 5 ha
- ☐ 5-10 ha
- ☐ 10-30 ha
- ☐ 30-60 ha
- ☐ More than 60 ha

6. **Most of the agricultural production on your farm is intended for:**

- ☐ Your own needs
- ☐ Selling

7. **Your farm is:**

- ☐ Conventional
- ☐ Integrated

☐ Ecological

☐ Biodynamic

8. What is your average yearly income from your farming activity?

☐ Less than 20.000€

☐ Between 20.000€ and 35.000€

☐ Between 35.000€ and 50.000€

☐ Between 50.000€ and 75.000€

☐ More than 75.000€

What proportion of your income is due to agriculture? _____%

9. On a scale from 1 to 7, how satisfied are you with your current production level?

Not enough			Satisfied			Too much
☐	☐	☐	☐	☐	☐	☐

10. What do you grown in your farm
11.

☐ Arable crops

☐ Mixed (livestock and arable crops)

- ☐ 0-5 LU
- ☐ 5-10 LU
- ☐ 10-30 LU
- ☐ 30-80 LU

☐ Livestock

- ☐ 0-5 LU
- ☐ 5-10 LU
- ☐ 10-30 LU
- ☐ 30-80 LU

☐ Orchards

☐ Vineyards

☐ Vegetables

☐ flowers

☐ Other (please specify)

12. Do you need to satisfy some legislative or market requirements (e.g. limits of fertilizers use, time of pesticide applications, …)?

☐ No

☐ Yes

Describe briefly:

13. Do you have a smartphone?

☐ No

☐ Yes

- For how many years: _____

- Do you use any agricultural help application?

☐ Yes

☐ No

14. Would you say you use it ...

☐ Not very much, less than most people around me

☐ Like most people around me

☐ More than most people around me

☐ Too much. I should try to use it less

15. Do you have a computer at home?

☐ Yes

Specify how often you use it and for what uses:

☐ No

Please give the main reason:

16. Do you have access to speed internet?

☐ No

☐ Yes, in the office but not in the fields

☐ Yes, both in the office and in the fields

17. Have you already used decision support systems?

☐ Yes

Which ones, mainly?

☐ No

Can you think of the main reason?

18. Usually, how do you access a DSS?

☐ Mobile phone
☐ PC
☐ Through an advisor

19. Which would be your preferred way to access a DSS?

☐ Mobile phone
☐ PC
☐ Through an advisor

20. Are you willing to try new products and services?

☐ Yes

☐ Sometimes

☐ Never

21. Is price an important factor of your decision to use or not a given decision support system?

☐ Yes

☐ No

22. In your opinion, decision support systems are more useful for

☐ Short-run decisions (for a specific problem at a specific time)

☐ Long-run decisions (to define my general pesticide management strategy)

23. What type of support do you prefer for a decision support system?

☐ Web-based

☐ Software downloaded locally

24. Please rate the from 1 (not important at all) to 7 (very important) the importance of the following characteristics for a support decision system:

"Easy to use"

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

"Efficient"

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

"Low price"

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

"Polyvalent" (can be used for several pests)

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

25. On a scale from 1 to 7, how much do you enjoy using new technologies?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

26. On a scale from 1 to 7, how much do you appreciate change in general?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

27. On a scale from 1 to 7, how much would you trust the guidance of a decision support system?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

28. On a scale from 1 to 7, much would you trust the advice of a colleague?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

29. On a scale from 1 to 7, much would you trust the advice of a friend?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

30. Would you need additional computer-related education?

☐ No

☐ If available, yes

☐ I need it urgently

31. Do you think that the use of a Decision Support tool may improve your decision-making process and productivity?

☐ No, not at all.

☐ I am not sure

☐ Probably

☐ Yes, for sure

32. Do you prefer a graphical or textual output from a decision support system?

☐ Graphical

☐ Textual

☐ Both

33. Do you exchange and share your experiences about the use of decision support systems with your colleagues?

☐ Never

☐ Occasionally

☐ Often

☐ Always

34. Do you use decision support systems from trusted sources?

☐ Don't care

☐ Always

35. Are you willing to pay in order to use a decision support system?

☐ No

☐ Only if a subsidy is available

☐ Yes

36. Would you consider necessary that a decision support system is tailored to your farm's characteristics?

☐ Not necessary

☐ Yes, if possible

☐ Required

37. Do you use the same decision support system as your advisor?

☐ No

☐ Similar but not the same

☐ The same

38. What is the age of the decision support system user at the farm?

☐ 18 – 30 years' old

☐ 30 – 45 years' old

☐ Older than 45

39. Do you have access to marketing information about decision support systems?

☐ No

☐ Occasionally only

☐ Yes, I'm subscribed to receive news concerning decision support systems

40. Have you followed a manufacturer's demonstration of a decision support system?

☐ Never

☐ Occasionally by invitation

☐ Regularly

41. In general terms, how would you imagine a platform integrating and giving access to several decision support systems? Comment next to each item below how important you consider it or leave the space blank otherwise.

Interface simplicity

Access to multiple DSS
Information to select DSS
The same user interface for all DSS
Risk alerts on one screen for multiple pests and multiple crops
Automatic alerts (via text or email)
Pest observations collected from users and providers

42. The tables below show a game with different payment options. Each payment is associated with a probability displayed in the table. The higher the payout, the lower the probability of obtaining it. For each of these panels, select the option you would prefer if you were playing this game.

PANEL 1

Prob. of Winning	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Euros	1	1.12	1.27	1.47	1.73	2.10	2.65	3.56	5.40	10.90
I prefer										

PANEL 2

Prob. of Winning	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Euros	1	1.20	1.50	1.90	2.30	3	4	5.70	9	19
I prefer										

PANEL 3

Prob. of Winning	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Euros	1	1.66	2.50	3.57	5	7	10	15	25	55
I prefer										

PANEL 4

Prob. of Winning	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Euros	1	2.20	3.80	5.70	8.30	12	17.50	26.70	45	100
I prefer										

Appendix C: Factor analysis for risk attitude elicitation

Table 5: Factor analysis of the lottery-panel risk elicitation task

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	2.802	2.641	1.019	1.019
2	0.161	0.251	0.059	1.077
3	-0.090	0.031	-0.033	1.044
4	-0.122	.	-0.044	1.000

LR test: independent vs. saturated: chi2(6) = 309.49 Prob>chi^2 = 0.0000

Table 6: Factor loadings (pattern matrix) and unique variances

Variable	Factor 1	Factor 2	Uniqueness
Risk Aversion 1	0.789	-0.250	0.314
Risk Aversion 2	0.911	-0.104	0.159
Risk Aversion 3	0.917	0.102	0.149
Risk Aversion 4	0.713	0.278	0.415

Table 7: PLS-SEM results for DSS use

Total effects: DSS use	Coefficient	STDEV	t-value	Confidence interval		p-value
				2.50%	97.50%	
Age -> DSS use	-0.010	0.008	1.291	-0.029	0.003	0.197
Age -> Enjoy using new technology	-0.238	0.076	3.132	-0.386	-0.084	0.002
Arable crops -> DSS use	0.180	0.058	3.103	0.082	0.309	0.002
Arable crops -> Farm size	1.075	0.249	4.314	0.615	1.588	0.000
DSS improves productivity -> DSS use	-0.036	0.029	1.258	-0.092	0.022	0.208
Easy of use -> DSS use	0.115	0.037	3.134	0.042	0.187	0.002
Enjoy using new technology -> DSS use	0.044	0.030	1.478	-0.013	0.103	0.140
Farm size -> DSS use	0.168	0.036	4.703	0.096	0.236	0.000
Income -> DSS use	0.072	0.020	3.634	0.036	0.112	0.000
Income -> Farm size	0.427	0.070	6.128	0.287	0.559	0.000
Legislative requirements (yes) -> DSS use	0.125	0.096	1.312	-0.062	0.315	0.190
Male -> DSS use	0.202	0.143	1.411	-0.088	0.469	0.158
Ocassional DSS demonstrations -> DSS use	0.104	0.055	1.907	-0.003	0.213	0.057
Unique crop -> DSS use	0.368	0.156	2.362	0.050	0.656	0.018
Male x Unique crop -> DSS use	-0.396	0.166	2.390	-0.706	-0.060	0.017

Table 8: PLS SEM results for WTP

Total effects: Willingess to pay (WTP)	Coefficient	STDEV	t-value	Confidence interval		p-value
				2.50%	97.50%	
Already used DSS -> WTP for DSS	0.194	0.093	2.091	0.015	0.383	0.037
Arable crops -> WTP for DSS	-0.307	0.112	2.750	-0.527	-0.085	0.006
Average risk aversion -> Trust in DSS	0.008	0.075	0.103	-0.149	0.145	0.918
Average risk aversion -> WTP for DSS	0.001	0.006	0.091	-0.011	0.013	0.927
DSS productivity -> WTP for DSS	-0.027	0.072	0.371	-0.168	0.122	0.711
Farm size -> WTP for DSS	0.105	0.041	2.553	0.025	0.188	0.011
Importance of low price -> WTP for DSS	-0.132	0.036	3.633	-0.199	-0.057	0.000
Income -> Farm size	0.507	0.066	7.713	0.369	0.627	0.000
Income -> WTP for DSS	0.053	0.023	2.295	0.012	0.103	0.022
Marketing info about DSS -> Trust in DSS	-0.733	0.481	1.523	-1.520	0.010	0.128
Marketing info about DSS -> WTP for DSS	-0.048	0.047	1.025	-0.134	0.016	0.306
Satisfaction with current production -> WTP for DSS	-0.048	0.032	1.489	-0.110	0.015	0.137
Sensitivity to risk -> Trust in DSS	-0.046	0.077	0.600	-0.193	0.107	0.548
Sensitivity to risk -> WTP for DSS	-0.003	0.006	0.483	-0.019	0.007	0.629
Trust in DSS -> WTP for DSS	0.066	0.042	1.582	-0.017	0.145	0.114
Trust in others -> Trust in DSS	0.271	0.076	3.585	0.132	0.419	0.000
Trust in others -> WTP for DSS	0.018	0.013	1.329	-0.004	0.048	0.184
Use same DSS as advisor -> DSS productivity	0.560	0.172	3.250	0.210	0.889	0.001
Use same DSS as advisor -> WTP for DSS	-0.015	0.043	0.354	-0.103	0.072	0.724
Willingness to try new products -> Trust in DSS	0.628	0.171	3.678	0.284	0.954	0.000
Willingness to try new products -> WTP for DSS	0.041	0.030	1.367	-0.010	0.108	0.172
Sensitivity to risk x Trust in others -> Trust in DSS	0.142	0.079	1.804	-0.017	0.289	0.071
Sensitivity to risk x Trust in others -> WTP for DSS	0.009	0.008	1.141	-0.004	0.028	0.254
Average risk aversion x Trust in others -> Trust in DSS	0.048	0.087	0.549	-0.112	0.229	0.583
Average risk aversion x Trust in others -> WTP for DSS	0.003	0.007	0.472	-0.008	0.019	0.637
Satisfaction with current production x Farm size -> WTP for DSS	0.058	0.033	1.733	-0.004	0.125	0.083
DSS productivity x Already used DSS -> WTP for DSS	0.151	0.081	1.881	-0.008	0.306	0.060

Table 9: VIF for variables directly influencing DSS use

Variable	VIF
DSS improves productivity	1.07
Easy of use	1.18
Enjoy using new technology	1.08
Farm size	1.20

Legislative requirements (yes)	1.19
Male	3.02
Ocassional DSS demonstrations	1.12
Unique crop	5.04
Male x Unique crop	6.74

Table 10: VIF for variables directly influencing WTP

Variable	VIF
Already used DSS	1.20
Arable crops	1.29
DSS productivity	5.11
Farm size	1.30
Importance of low price	1.06
Satisfaction with current production	1.12
Trust in DSS	1.27
Satisfaction with current production x Farm size	1.07
DSS productivity x Already used DSS	4.26

6 References

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology*, *2*(1), 1. https://doi.org/10.2478/V10102-009-0001-7

Alenljung, B. (2008). Envisioning a Future Decision Support System for Requirements Engineering – A Holistic and Human-centred Perspective. In *PhD Thesis, Department of Computer and Information Science, Linköpings universitet SE-581 83 Linköping, Sweden* (Issue 1155).

Aubert, B. A., Schroeder, A., & Grimaudo, J. (2012). IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology. *Decision Support Systems*, *54*(1), 510–520. https://doi.org/10.1016/j.dss.2012.07.002

Auld, B. A., & Tisdell, C. A. (1987). Economic thresholds and response to uncertainty in weed control. *Agricultural Systems*, *25*(3), 219–227. https://doi.org/10.1016/0308-521X(87)90021-7

Barzman, M., Bàrberi, P., Nicholas, & A., Birch, E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., Hommel, B., Jensen, J. E., Kiss, J., Lamichhane, J. R., Messéan, A., Moonen, A.-C., Ratnadass, A., Ricci, P., Sarah, J.-L., & Sattin, M. (2015). Eight principles of integrated pest management Agroscope Changins-Wädenswil ACW, Plant Protection and Fruit and Vegetable Extension. *Agron. Sustain. Dev*, *35*, 1199–1215. https://doi.org/10.1007/s13593-015-0327-9

Damos, P. (2015). Modular structure of web-based decision support systems for integrated pest management. A review. *Agronomy for Sustainable Development*, *35*(4), 1347–1372. https://doi.org/10.1007/S13593-015-0319-9/TABLES/1

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly: Management Information Systems*, *13*(3), 319–339. https://doi.org/10.2307/249008

de la Fuente, B., Saura, S., & Beck, P. S. A. (2018). Predicting the spread of an invasive tree pest: The pine wood nematode in Southern Europe. *Journal of Applied Ecology*, *55*(5), 2374–2385. https://doi.org/10.1111/1365-2664.13177

Eastwood, C. R., Chapman, D. F., & Paine, M. S. (2012). Networks of practice for co-construction of agricultural decision support systems: Case studies of precision dairy farms in Australia. *Agricultural Systems*, *108*, 10–18. https://doi.org/10.1016/j.agsy.2011.12.005

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations. A review. In *Technological Forecasting and Social Change* (Vol. 43, Issues 3–4, pp. 215–239). North-Holland. https://doi.org/10.1016/0040-1625(93)90053-A

Fountas, S., Blackmore, S., Ess, D., Hawkins, S., Blumhoff, G., Lowenberg-Deboer, J., & Sorensen, C. G. (2005). Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt. *Precision Agriculture*, *6*(2), 121–141. https://doi.org/10.1007/s11119-004-1030-z

Higley, L. G., & Pedigo, L. P. (1996). Economic thresholds for integrated pest management. *Our Sustainable Future (USA)*. https://agris.fao.org/agris-search/search.do?recordID=US9735362

Kuehne, G., Llewellyn, R., Pannell, D. J., Wilkinson, R., Dolling, P., Ouzman, J., & Ewing, M. (2017). Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy. *Agricultural Systems*, *156*, 115–125. https://doi.org/10.1016/j.agsy.2017.06.007

Kumar, G., Engle, C., & Tucker, C. (2018). Factors Driving Aquaculture Technology Adoption. *Journal of the World Aquaculture Society*, *49*(3), 447–476. https://doi.org/10.1111/jwas.12514

Marinko, J., Ivanovska, A., Marzidovšek, M., Ramsden, M., & Debeljak, M. (2023). Incentives and barriers to adoption of decision support systems in integrated pest management among farmers and farm advisors in Europe. *International Journal of Pest Management*. https://doi.org/10.1080/09670874.2023.2244912

McCown, R. L., Carberry, P. S., Hochman, Z., Dalgliesh, N. P., & Foale, M. A. (2009). Re-inventing model-based decision support with Australian dryland farmers. 1. Changing intervention concepts

during 17 years of action research. *Crop and Pasture Science*, *60*(11), 1017. https://doi.org/10.1071/CP08455

McDonald, R., Heanue, K., Pierce, K., & Horan, B. (2016). Factors Influencing New Entrant Dairy Farmer's Decision-making Process around Technology Adoption. *Journal of Agricultural Education and Extension*, *22*(2), 163–177. https://doi.org/10.1080/1389224X.2015.1026364

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability*, *13*(1), 40–54. https://doi.org/10.1080/14735903.2014.912493

Neeser, C., Dille, J. A., Krishnan, G., Mortensen, D. A., Rawlinson, J. T., Martin, A. R., & Bills, L. B. (2004). WeedSOFT®: A weed management decision support system. *Weed Science*, *52*(1), 115–122. https://doi.org/10.1614/P2002-154

Oliveira, C. M., Auad, A. M., Mendes, S. M., & Frizzas, M. R. (2014). Crop losses and the economic impact of insect pests on Brazilian agriculture. *Crop Protection*, *56*, 50–54. https://doi.org/10.1016/J.CROPRO.2013.10.022

Ramsden, M. W., Kendall, S. L., Ellis, S. A., & Berry, P. M. (2017). A review of economic thresholds for invertebrate pests in UK arable crops. *Crop Protection*, *96*, 30–43. https://doi.org/10.1016/J.CROPRO.2017.01.009

Rossi, V., Salinari, F., Poni, S., Caffi, T., & Bettati, T. (2014). Addressing the implementation problem in agricultural decision support systems: The example of vite.net®. *Computers and Electronics in Agriculture*, *100*, 88–99. https://doi.org/10.1016/j.compag.2013.10.011

Sabater-Grande, G., & Georgantzis, N. (2002). Accounting for risk aversion in repeated prisoners' dilemma games: an experimental test. *Journal of Economic Behavior & Organization*, *48*(1), 37–50. https://ideas.repec.org/a/eee/jeborg/v48y2002i1p37-50.html

Seem, R. C., & Russo, J. M. (1984). Simple decision aids for practical control of pests. *Plant Disease*, *66*(8), 656–660. https://www.apsnet.org/publications/plantdisease/backissues/Documents/1984Articles/PlantDisease68n08_656.PDF

Shtienberg, D. (2013). Will Decision-Support Systems Be Widely Used for the Management of Plant Diseases? *Http://Dx.Doi.Org/10.1146/Annurev-Phyto-082712-102244*, *51*, 1–16. https://doi.org/10.1146/ANNUREV-PHYTO-082712-102244

Thorburn, P. J., Jakku, E., Webster, A. J., & Everingham, Y. L. (2011). Agricultural decision support systems facilitating co-learning: A case study on environmental impacts of sugarcane production. *International Journal of Agricultural Sustainability*, *9*(2), 322–333. https://doi.org/10.1080/14735903.2011.582359

Van Meensel, J., Lauwers, L., Kempen, I., Dessein, J., & Van Huylenbroeck, G. (2012a). Effect of a participatory approach on the successful development of agricultural decision support systems: The case of Pigs2win. *Decision Support Systems*, *54*(1), 164–172. https://doi.org/10.1016/j.dss.2012.05.002

Van Meensel, J., Lauwers, L., Kempen, I., Dessein, J., & Van Huylenbroeck, G. (2012b). Effect of a participatory approach on the successful development of agricultural decision support systems: The case of Pigs2win. *Decision Support Systems*, *54*(1), 164–172. https://doi.org/10.1016/j.dss.2012.05.002

Zhiembayev, Z., Afonin, A., Kopzhassarov, B., Milyutina, E., Kazakov, E., Sarbassova, A., & Seisenova, A. (2020). Prototype Spatio-temporal Predictive System of pest development of the codling moth, Cydia pomonella, in Kazakhstan. *Hellenic Plant Protection Journal*, *13*, 1–12. https://doi.org/10.2478/hppj-2020-0001