



Decision support tools for agriculture: Towards effective design and delivery

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ABSTRACT

Decision support tools, usually considered to be software-based, may be an important part of the quest for evidence-based decision-making in agriculture to improve productivity and environmental outputs. These tools can lead users through clear steps and suggest optimal decision paths or may act more as information sources to improve the evidence base for decisions. Yet, despite their availability in a wide range of formats, studies in several countries have shown uptake to be disappointingly low. This paper uses a mixed methods approach to investigate the factors affecting the uptake and use of decision support tools by farmers and advisers in the UK. Through a combination of qualitative interviews and quantitative surveys, we found that fifteen factors are influential in convincing farmers and advisers to use decision support tools, which include usability, cost-effectiveness, performance, relevance to user, and compatibility with compliance demands. This study finds a plethora of agricultural decision support tools in operation in the UK, yet, like other studies, shows that their uptake is low. A better understanding of the fifteen factors identified should lead to more effective design and delivery of tools in the future.

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1. Introduction

Decision support tools (DST) are designed to help users make more effective decisions by leading them through clear decision stages and presenting the likelihood of various outcomes resulting from different options (Dicks et al., 2014; Parker, 2004). These can be dynamic software tools, whose recommendations vary according to the user's inputs, and they may suggest an optimal decision path. For farmers, and their advisers, software tools can facilitate effective farm management by recording data efficiently, analysing it, and generating a series of evidence-based recommendations (Rossi et al., 2014). Other DST may not be dynamic but act more as information sources. However, despite their apparent value the uptake of DST by farmers and advisers in the UK, and elsewhere, has been limited (Alvarez and Nuthall, 2006; Gent et al., 2013; McCown, 2002; Parker et al., 1997). There has been relatively little investigation into decision support uptake by farmers in the UK,

but studies elsewhere (e.g. Australia, Belgium, Italy) have developed a number of important characteristics that determine use (Hochman and Carberry, 2011; Kerr, 2004; Kerselaers et al., 2015; McCown, 2012; Rossi et al., 2014). Research into appealing characteristics has also been undertaken in different disciplines, especially medicine; this work provides useful insights for an agricultural audience (Shibl et al., 2013; Venkatesh et al., 2012). Yet despite sustained interest from inter-disciplinary researchers, uptake is still low. This is especially problematic since projects to design DST are often expensive.

In this paper, we do not seek to argue that farmers and advisers should use multiple DST, since the quality and effectiveness of tools is more important than the quantity used. Rather, we note that there are already a number of high-quality DST available, with many more in the conception and design phase. Therefore, to assist the delivery of existing tools, and the design of future tools, we identify a number of key characteristics affecting the use of DST by farmers and advisers in the UK. We identify fifteen factors that should be considered in the design and delivery of successful DST. Many of these are relevant to software-based, app-based, or paper-based tools, and also to tools

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developed outside of the UK. If the designers of DST can be encouraged to apply the findings from this study as a checklist against which to measure the quality of new tools, then the likelihood of a tool's uptake in on-farm decision making will be increased.

2. Methods

2.1. Expert-collated list

Based on a broad definition of a decision support tool, which includes bespoke or generic software, email/text alerts, online calculators or guidance, phone apps, and paper-based guidance, an initial list was created of tools that could contribute to a farming decision (including business decisions) in the UK. As a consequence, decision support tools (DST) relating to many aspects of farm management were eligible for the list, including business and accounting tools and general information sources. The list does not include 'human-based' decision support tools, such as advisers or peers. Full search terms, criteria for inclusion, details of experts, and the resulting list can be found in Appendix 1.

2.1.1. Compiling initial list

Firstly, a review of literature on DST identified a number of tools available for use in the UK. Secondly, an online search was undertaken through Google, in combination with the websites of large companies, levy boards and research organisations connected to the arable and live-stock enterprises. Thirdly, a non-exhaustive list of apps was compiled by searching on both the Android and iOS app stores. The original list comprised 129 tools.

2.1.2. Adding to the list

The list was supplemented by agricultural experts, who were given the same definition of a decision support tool and the same criteria for inclusion. This list was sent to known experts, who were also encouraged to send it to colleagues. A designated space was left for respondents to add further DST to the list and these additions were checked on return. Experts returned 24 lists of tools within one month, with many of these including contributions from a number of different individuals. Of the 24 returned lists, five respondents across at least two

enterprises could not make any further additions, and the list was closed upon the fifth non-addition. This list was then supplemented by a wider consultation of the iOS and Android app stores (see Appendix 1).

2.2. Survey

A survey of farmers was undertaken in seven study areas across England and Wales (Fig. 1). These areas were chosen to represent some of the key agricultural land use types and geographies across England and Wales as part of Defra's Sustainable Intensification Platform (SIP). A sample of farmers was drawn from Defra from the June Agricultural Survey Register (2013), which groups similar farms by type to allow comparison. Six different robust farm types were surveyed: 'Arable', 'Dairy', 'Lowland Grazing', 'LFA Grazing', 'Mixed', and 'General Cropping', which account for the vast majority of agricultural land cover (National Statistics, 2016).

The sample of farms in each survey area, provided by Defra/Welsh Government, was stratified to reflect the main farm types in each area. Any robust farm types accounting for less than 10% of the case study area population were excluded. Farms were selected to give good geographical coverage of each area. In addition, to be included in the sample each holding had to meet the criteria of being a 'commercial holding' as well as farming a minimum of 20 ha. Registered holders were sent an opt out letter giving five working days to opt out of being telephoned to be invited to take part in an interview. 220 farmers (approximately 14% of the original sample) chose to opt out and a further 611 (38%) were uncontactable (including those who never answered the phone or where contact details were incorrect), leaving an effective sample of 782. 244 of these responded positively when contacted and telephone and were then interviewed face-to-face.

The survey asked a range of questions relevant to on-farm decision-making (Appendix 2), but two questions in particular related to use of DST. Farmers were asked whether they used software, apps, or paper-based guidance to inform their decisions and asked to name up to three that they found most useful. A list of the most commonly used tools was generated and categorised by mode of delivery (Appendix 1).

The survey was quantitatively analysed to generate overall usage data, and to look for significant associations between the use of DST and other factors. Generalised linear models assuming a binomial

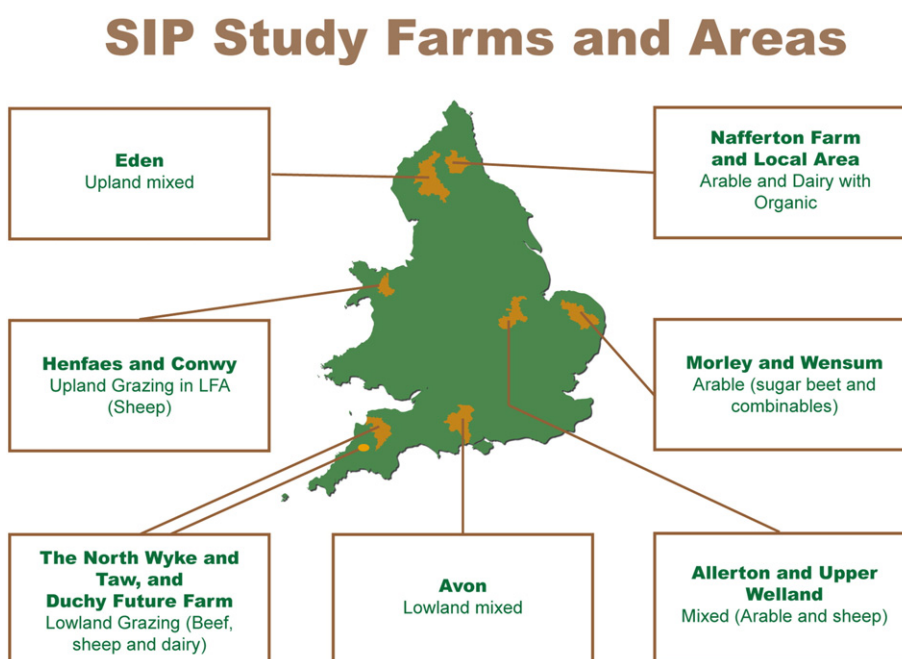


Fig. 1. Study areas for survey.

distribution were used to test the association between two response variables (use of DST [$n = 226$] and use of software [$n = 209$]) and the following seven explanatory variables:

- Farm size (ha).
- Economic happiness (given a score of 1–4 based on a categorical Likert scale illustrated in the baseline survey, see Appendix 2).
- Income compared with England/Wales average (scored 1–5 as above).
- Production satisfaction (scored 1–4 as above).
- Education (scored 1–5 as above).
- Age.
- Farm type (categorical variables: cereals, dairy, lowland grazing, least favoured area grazing, mixed, general cropping).

Entries with missing data were excluded from the analysis. The analysis was conducted using R 3.0.0 (R Core Team, 2013).

2.3. Semi-structured interviews

Following the baseline survey, 78 interviews were conducted with farmers and advisers in three of the study areas (Wensum, Taw and Conwy). It was important to interview farm advisers as several studies have demonstrated the value of advisers for on-farm decision-making (ADAS, 2012; AIC, 2013; Dampney et al., 2001; Ingram, 2008; Prager and Thomson, 2014; Winter, 1996; Winter et al., 2000a; Winter et al., 2000b). 18 livestock consultants from the dairy and beef/sheep enterprises (Taw and Conwy) and 15 arable advisers (Wensum) were interviewed. These interviewees offered business, technical, or environmental advice to farmers, including land agents, agronomists, and livestock consultants. These were joined by 45 farmers across three study regions, mainly covering the arable (14 in Wensum), upland livestock (LFA - 19 across Taw/Conwy), and lowland livestock enterprises (9 across Taw/Conwy), but also including dairy (3 across Taw/Conwy). The farmers were recruited from those who had completed the quantitative survey and were willing to take part in future research. Interviewees were then selected to generate a good range of farm sizes, ages, and including examples of those who answered 'Yes' or 'No' to use of decision support.

The adviser sample was generated with assistance from ADAS. For each enterprise, a search was conducted to identify any company or organisation that provided advisory services within the catchment area specified for the interviews (arable advisers from the Wensum catchment, livestock advisers from the Taw or Conwy catchments). This was done through known contacts of ADAS colleagues and searches for advisory services and online search engines. Once these resources were exhausted, contact details for the individual deemed most appropriate in the company or organisation identified were collated into an extensive list. After initial contact, a core list of interested participants was collated for the main project team to then select individuals for the interviews. Given the relatively low numbers of advisors in the catchment areas, this methodology was deemed robust as at least one individual from all known advisory companies were contacted and offered the opportunity to participate.

The interview questions were guided by previous literature, with some flexibility to pursue new lines of enquiry. In the work of Kuehne et al. (2011) on predicting innovation adoption they suggested that two overarching factors affected the uptake of new innovations, which is a useful proxy for DST. Firstly, they acknowledged the importance of 'learnability' characteristics, or those factors that determine how the end user finds out about a new innovation. Secondly, the 'relative advantage' of the innovation must be recognised, in other words the end user must be convinced that uptake and use of an innovation is better than sticking to the *status quo* (Kuehne et al., 2011). The sample interview in Appendix 3 comprised each of these elements, and allowed respondents to speak widely about the factors influencing their use of different kinds of DST. The interviews were recorded, transcribed, and coded qualitatively with Atlas.Ti software to identify key recurring themes.

2.4. Workshop

A total of 39 researchers, policy-makers, industry representatives, and decision support tool manufacturers (see Appendix 4) attended a one-day workshop. Attendees representing different software and app manufacturers were invited if their tool had attracted significant attention across the baseline survey and interviews. Each of the manufacturers was asked to give a presentation describing the purpose of their system and the factors that they had considered when designing the system. The content of their presentations was coded according to the factors shown in Fig. 2 to see if there was a correlation between design considerations and end user preferences (Appendix 4).

3. Results

3.1. Availability and usage of DST

The list of DST available to UK farmers and advisers comprised 395 different tools (Appendix 1). This list is not exhaustive, with new tools being designed regularly and a swathe of non-farming specific tools (e.g. accounting packages) not fully captured by the methodology. Whilst the list is non-exhaustive, and further does not comment on the quality of each individual tool, it does illustrate the level of choice facing farmers and advisers. In addition to this list of available tools in the UK, a second list of the systems actually being used in practice was generated by the survey (and 33 advisers in interview). This list included 73 different tools (Appendix 1).

Despite the existence of so many types of DST, the survey found use to be mixed. Overall, 49% of farmers used some kind of decision support tool to inform decisions, and the modes of delivery found to be most useful were software (28%), paper-based (22%) and apps (10%). Although a quantitative analysis of 33 adviser interviews was not appropriate, findings suggested that usage of decision support was much higher amongst this group. In fact, every adviser interviewed used some form of decision support on a regular basis, particularly software-based and paper-based tools. Despite being more likely to utilise DST, advisers tended to use a small selection of common ones.

3.2. Key factors influencing use of a decision support tool

Fig. 2 presents the key factors that were found to influence the uptake and use of DST in the interviews across the three study areas. All of these are relevant to varying degrees across all types of DST, whether computer-based, app-based, or paper-based.

For successful uptake of DST, researchers and designers should consider the following fifteen factors (* = mentioned most often):

3.2.1. Core factors

The core factors presented in Fig. 2 directly influence behavioural intention to use a specific decision support tool. These factors are not mutually exclusive and the strength of each can be modified by other variables.

*Performance expectancy**

The performance of a decision support tool was a widely mentioned factor determining use. Irrespective of whether the mode of delivery was via software, apps, or paper, both farmers and advisers wanted it to improve decision-making and productivity. The desire for a tool to perform well was summarised by one farmer who asked "at the end of the day how is it going to benefit the business...how is it going to benefit it financially?" (Arable adviser, Wensum, 12). An arable farmer, for example, praised a tool because it directly contributed to improved yields 'within the space of three or four years' (Arable farmer, Wensum, 52076). If the tool does not provide tangible benefits, or if a farmer does not 'perceive a benefit' (Livestock adviser, Taw, 10) then it is likely not to be used. DST should work efficiently, provide up-to-date information,

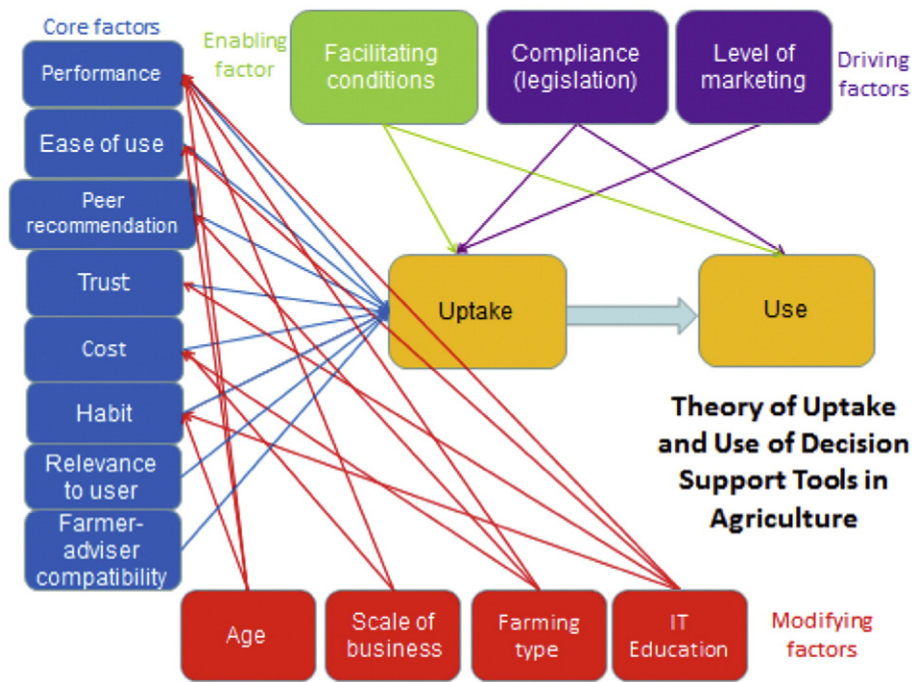


Fig. 2. Theory of uptake and use of DST in agriculture.¹

give accurate predictions or information, and enable better decision-making. Furthermore, DST must be readily updated after release for continued accuracy.

*Ease of use**

It is important that a decision support tool provides information in a quick, user-friendly way. Farmers suggested that a tool “has got to be really simple and user-friendly to be able to understand” and must provide “instantaneous information” (Arable farmer, Wensum, 52039). Both farmers and advisers have busy schedules and therefore the time taken to extract information from a tool was a key factor. Advisers felt that they needed to communicate information in a clear way to farmers, and valued tools that enabled them to do this. Visual presentation of decision-making information was considered to be the best way to increase the user-friendliness of a tool. An adviser suggested that his clients used a specific tool because:

“...it has got pretty graphs on it. And that isn't being dismissive of the data that farmers would look at but...we are guilty of sending farmers a heap of information and figures and it's just too much. They want something quick, easy to look at.”

(Livestock adviser, Conwy, 8).

An arable farmer also suggested how a crop recording programme could be improved by making it more visual. They argued that the current problem was:

“...there's too much text. It's just little bit of writing everywhere. I think visualisation is the key...with the things that machines can do, it would be nice to have a map.”

(Arable farmer, Wensum, 52000).

If a tool was not simple and intuitive, or in the words of one adviser “too bloody complicated” (Arable adviser, Wensum, 5), then the end

user quickly lost patience or felt inclined “to cheerfully throw [their] computer through the window” (Livestock adviser, Taw, 10). One particular adviser recalled a training course he had given on a software package designed for improving NPK application:

“Farmers couldn't understand it [computer system]...we tried to make them, but they could hold the information for about half a day. I think if it is user friendly and it doesn't ask for too much information, then it's ok.”

(Livestock Adviser, Taw, 1).

Ease of use was, therefore, one of the most influential reasons why a particular decision support tool was used or not.

*Peer recommendation**

Peer recommendation, either between farmer or adviser networks, was a key determinant of uptake. One farmer suggested that he had “a lot of different contacts” so if he “wanted to find out something” (Lowland farmer, Taw, 10019) then he would use these existing networks of trusted peers. In fact, farmers argued strongly that “the best way of disseminating information is to put ten farmers together [to] share their experiences” (Lowland farmer, Taw, 10011). These shared experiences could include the use of DST, which both farmers and advisers would try out if peers had praised them. For example, an agronomist recalled why they had started using a particular crop health and protection programme:

“I was discussing merging with another two colleagues and we started discussing it about 15 or 20 years ago. They were using this system and thought that I should get into it...so I went into it for that reason.”

(Arable adviser, Wensum, 2).

In addition, a farmer remembered why he first decided to try out a smartphone app to aid crop growth:

“...you have a chat with your neighbours and they say have you seen this app and you have a look at it and think oh that's quite handy.”

¹ The wording and format of the diagram amends the categorisation used by Venkatesh et al. (2012), who developed a ‘Unified Theory of Acceptance and Use of Technology’. The work of Shibl et al. (2013) on the usage of decision support tools in the medical field was also drawn upon.

(Arable farmer, Wensum, 52039).

(LFA farmer, Conwy, 20030).

Hence, it is clear that peer recommendation can help to spread the message about the availability and usefulness of a decision support tool, which can in turn encourage uptake.

Trust

Trust in a decision support tool determined whether it was used in practice. Both farmers and advisers were keen to use tools from trusted sources, whilst advisers were particularly concerned with the evidence-base behind tool development. For example, an agronomist illustrated their thought process about tool provenance before deciding whether to use it:

"Well if it was made by HGCA [now AHDB Cereals and Oilseeds] I would have trust...If it's manufacturer led, depending on who the manufacturer is and the research base I would be about 50%. And some tools I wouldn't even pick up if I didn't have faith in the manufacturer."

(Arable adviser, Wensum, 7).

In addition, DST were trusted by advisers if the evidence-base supporting them was robust and transparent. One adviser commented:

"You have to know where the algorithms are coming from...if they're based on good science you can take it into account, otherwise we simply wouldn't use it."

(Arable adviser, Wensum, 11).

It was apparent that if advisers trusted the evidence-base behind a tool, then they would be happy to use it regularly. Referring to a rationing programme designed at improving productivity from better animal nutrition, a livestock consultant argued that:

"It is very good in terms of it having a very good library of information behind it. We use that one because it is technically sound. The science behind it was good, the pedigree of where it comes from is good... I think we trust the answers fairly well."

(Livestock adviser, Taw, 16).

However, if advisers used a tool and could not be satisfied as to the rigour of its evidence-base, then it was unlikely to be used again. DST should therefore be developed and presented in a way that builds trust with the end user.

*Cost**

The cost of a decision support tool affected its uptake by the end user. Tools were more likely to be trialled if they were free or if a grant was provided for purchase. Sometimes even a small cost was off-putting because "when you are working on a small budget...and you spend £5 too much it is going to hurt and you are going to still be feeling the pain next year on the farming side" (LFA farmer, Conwy, 20028). Many farmers said that they could not "afford a computer" (LFA farmer, Conwy, 20020), whilst others suggested that if "there was to be a benefit to it", and cash was available, then they "would use it even if you had to pay for it" (Arable farmer, Wensum, 52076). Evidence suggested that advisers were better able to pay for systems, particularly if colleagues within the same company bought a tool collectively and shared the cost.

In light of concerns over cost, the data illustrated that tool uptake was higher where grant funding was provided. For example, a farmer in Conwy said that:

"I've just bought a computer programme and a digital tag reader funded by Farming Connect, which was a great help for us. It's a help to get something that you've always wanted because it's hard to pay for things."

Other farmers in Conwy suggested that they would not have bought software without grant funding. DST are therefore more likely to be used if they are inexpensive.

*Habit**

Habit was a significant factor affecting use. A regular tendency to make a decision in a particular way holds back the uptake of new ideas, particularly modern technology like software and apps. For example, a farmer's wife suggested that her husband "doesn't like technology and hasn't even got a mobile phone. He's never used a computer in his life. That is the way he likes it." (Arable farmer, Wensum, 52076). Others were happy with the way "they've always done it" (Arable farmer, Wensum 51072) and were content to be "old-fashioned" (Lowland farmer, Taw, 10011). It is not necessarily that a user cannot learn to make decision in a new way; rather there can be a deep-seated aversion or "fear" (Lowland farmer, Conwy, 20009) of trying things out in the first place.

In contrast, farmers thought that "the younger generation are growing up with it [technology] and treat it like I used to treat driving" (Arable farmer, Wensum, 51003). Since younger farmers are used to using computers and smartphones, it is likely that they will seamlessly start to use a decision support tool delivered in the form of software or apps. Even those farmers who had embraced software-based decision support indicated that they would find it hard to move away from their current tools if new ones were developed. Therefore, habit is probably one of the most difficult factors to overcome, as it will not be affected by designing more user-friendly systems that perform better.

Relevance to user

DST should be sufficiently flexible to serve the needs of an individual user. Speaking generally about guidance provided on information sheets, one farmer argued that good advice should be "tailored to your situation, rather than just be generic." He also added that whilst using guidance documents "sometimes you feel like they're just talking about somewhere else." (LFA farmer, Conwy, 20018). In particular, the ability of a decision support tool to be tweaked according to individual farm variations (e.g. soil, field slope) was deemed important. The desired "personal approach to farm" (Arable farmer, Wensum, 52000) included the ability of a tool to predict or account for differences in local weather conditions. An arable farmer reported that:

"In the last month we know that between our three farms, the rainfall totals on those farmers are vastly different. So we are dealing with that, although we are all growing wheat, we are dealing with very different situations in our crops. That brings it down to the accuracy of any decision support system."

(Arable farmer, Wensum, 51011).

Therefore, if DST are insufficiently flexible to allow farmers and advisers to account for local variations, then the end user will consider it to be unsuitable for their situation.

Farmer-adviser compatibility

As well as trying new tools out on the recommendations of peers, both farmers and advisers discussed how knowledge exchange between the two groups facilitated the use of DST. For example, advisers reported that they "encourage clients to sign up for tools" (Livestock adviser, Conwy, 8), and farmers widely stated that they "found out about tools through the agronomist" (Arable farmer, Wensum, 51007) or had to change their crop recording tools whenever their adviser did so. Conversely, advisers were also influenced by what their clients were using. Since advisers are providing a service to farmers, then much of their work was "customer driven" (Livestock adviser, Taw, 12). This included the need to analyse data produced by a farmer-used

tool, so if a client used a specific tool, then the adviser would need to follow suit.

3.2.2. Modifying factors

The modifying factors shown on Fig. 2 do not directly affect behavioural intention to use a decision support tool. Instead, they modify the strength of the core factors, which in turn affects uptake. Questions asked in the baseline survey² (Appendix 2) allowed the effects of modifying factors to be statistically analysed to determine their importance. The factors presented below had either a significant association with use of DST, or suggested a correlation.

Age*

Age was a significant determinant of DST, particularly the use of computer software. It affected whether a user thought that a high-tech tool could be beneficial or easy to use; it also determined the strength of deeply-rooted decision-making habits. Older farmers knew “quite a few of [their] generation that don't use a computer” (LFA farmer, Conwy, 20014) and many were “of an age where [they] were half afraid of computers” (Lowland farmer, Taw, 10012). The average age of farmers in the UK is around 59 (National Statistics, 2016), which is similar to the average of farmers surveyed here (57). Older farmers noted that “most of the young farmers are on computers and things” (LFA farmer, Conwy, 20014) and this suggests a relationship between the mode of delivery of DST and uptake.

In contrast, advisers generally used age as less of an excuse for not embracing technical DST. An agronomist argued that their clients “relied” on them to make technical decisions because farmers are “far too busy” (Arable adviser, Wensum, 7). Other advisers suggested that their clients “don't think that using decision support is their role in lots of respects” (Arable adviser, Wensum, 10) and therefore had to use DST themselves in order to compensate for this.

Referring to DST generally (including software, apps, paper, online), age had a significantly negative association with the use of DST indicating that younger farmers use DST more (Table 1 and Fig. 3a).

The analysis also suggested a significant negative relationship between a user's age and finding software most useful (Table 2 and Fig. 3b).

Scale of farming

The scale of a farm modified several core factors, particularly the cost/performance benefit of using a tool. Farmers suggested that tools, such as recording software, were useful for larger scales since the amount of data produced on such farms was much greater. Larger farmers were likely to employ more staff, some of whom would be tasked with using DST. For a small landholding, however, DST were deemed less useful and many farmers were “not in any way near the point where tools would become necessary” (Lowland farmer, Wensum, 51064). A small upland farmer in Conwy responded:

“What the **** do I need it for? We're talking about a small mountain farm, you're not talking about a farm down in Cambridgeshire or Lincolnshire who's got a thousand acres, different crops in every field, then you'll need a decent computer.”

(LFA farmer, Conwy 20034).

A fellow upland farmer agreed with this sentiment and suggested that because he had “only got two hundred ewes, it's not worth bothering”. He went on to say that “if I had two thousand, maybe I would get something” (LFA farmer, Conwy, 20018).

Table 1

Results of the generalised linear model testing the relationship between the use of DST and seven explanatory variables. Significant factors are shown in bold.

Coefficients	Estimates	SE	z value	p
Intercept	2.986	1.420	2.103	0.036*
Farm size	0.001	0.001	2.080	0.038*
Economic happiness	−0.125	0.204	−0.613	0.540
Income	0.217	0.133	1.631	0.103
Production satisfaction	−0.145	0.274	−0.531	0.596
Education	0.111	0.144	0.768	0.443
Age	− 0.045	0.015	− 2.994	0.003**
Farm type (dairy)	− 1.908	0.658	− 2.899	0.004**
Farm type (LFA)	−0.847	0.439	−1.928	0.054
Farm type (lowland)	− 0.194	0.448	− 4.328	0.015 × 10^{3***}
Farm type (mixed)	−0.769	0.623	−1.235	0.217
Farm type (general cropping)	− 1.487	0.742	− 2.005	0.005*

Statistical analysis showed that the probability of using DST is higher in larger farms (Table 1 and Fig. 3c).

Farming type

Closely linked to the scale of farming, farm type was also a key determinant of decision support tool use. A livestock adviser suggested that the collection of data varied between farm types:

“I think it's the ease of collecting data. You can sit round a table with a dairy farmer and there's an awful lot of figures to hand because they need to be there for the business. Whereas if you go to a sheep farmer in Conwy, and the sheep are on the mountain, he doesn't even know how many animals he's got, never mind whether they're performing”.

(Livestock adviser, Conwy, 8).

Therefore, beef/sheep farmers in particular were deemed to need DST less “because they've got nothing to input” (Livestock adviser, Conwy, 7). In general, upland livestock farming was considered a simpler system, and therefore the performance benefits of a decision support tool were thought to be lower. In contrast, farmers and advisers in the arable and dairy enterprises painted a complex picture, in which there was a plethora of data for tools to manipulate and suggest productive decisions. Agronomists, dairy consultants, and farmers in these two enterprises were therefore more likely to need DST.

The analysis showed that the probability of DST use is significantly lower in Dairy, Lowland Grazing and General Cropping, compared to Cereals (Table 1 and Fig. 3e). Similarly, the probability of finding software useful was significantly lower in LFA, Lowland Grazing, compared to Cereals (Table 2 and Fig. 3f).

IT education*

The factor of IT education links closely with age, habit, and effort expectancy. One farmer suggested that his lack of IT education meant that he preferred paper-based DST:

“I am anti-technology before I start, so that is a problem. I am much happier with books and magazines and things I am comfortable with. I am not comfortable with anything that is electronically pressing a button. I don't like the phones even, the modern phones.”

(Arable farmer, Wensum, 51003).

IT education has undergone a step-change in recent decades, and therefore younger farmers/advisers have been exposed to IT far more than previous generations. A farmer described himself as a “technophobe, not out of choice, but because somehow or other I was left behind” (Arable farmer, Wensum, 51072). A further enlightening statement came from an arable farmer recalling his time at Harper Adams University:

² The baseline survey was designed before the interviews and therefore could not foresee many of the factors that were found to be important in the interviews. However, since the baseline survey asked questions relevant to the modifying factors, which were found to be important subsequently in interviews, it was sensible to use statistical tests referring to the relationships between these factors and use of DST.

Fig. 3. Logistic regression analysis of (A) age and use of DST, (B) age and finding software most useful, (C) farmed area and use of DST, (D) education and finding software most useful, and proportional analysis of (E) farm type and use of DST, (F) farm type and finding software most useful. Sample explanation for (A) - here the histogram above the line indicates the age of farmers using DST, and the histogram below shows that of farmers not using DST. The red line represents the estimated relationship between farmers' age and the use of DST, showing younger farmers tend to use DST more. GC = General Cropping.

"My son is forever exchanging information on their iPad because that's been part of their education hasn't it? When I left college there was a computer at Harper Adams Agricultural College. It occupied a room about four times the size of this."

(Arable farmer, Wensum, 51072).

Lack of IT education was the main reason why the majority of farmers liked DST in the form of paper, usually comprising factsheets designed to provide vital information. Many farmers, however, suggested that they would be interested in using software "if someone showed [them] how" (Lowland farmer, Taw, 10019).

Again, as with age, advisers suggested that lack of IT education could not be an excuse for failing to embrace new technologies. Advisers

argued that their time was spent making technical decisions and using DST, and therefore they had "a reasonable hold on them" (Arable adviser, Wensum, 11). Since farmers "increasingly delegate technical decisions" (Arable adviser, Wensum, 11), advisers had systems in place to access professional training through their companies and sometimes had a "dedicated IT department" (Arable adviser, Wensum, 8) to help them keep up with advances.

Although the baseline survey did not ask about IT education specifically, it did ask farmers about levels of education on a scale from GCSEs to post-graduate qualifications. Whilst this is not the same as IT education, results may be used as a reasonable proxy for its likely impact on software use. Statistical analysis revealed a significant positive effect of education, suggesting that those with higher qualifications found software most useful (Table 2 and Fig. 3d).

Table 2

Results of the generalised linear model testing the relationship between finding software most useful and seven explanatory variables. Significant factors shown in bold.

Coefficients	Estimates	SE	z value	p
Intercept	−0.116	1.491	−0.078	0.938
Farm size	0.001	0.004 × 10 ¹	1.233	0.218
Economic happiness	−0.016	0.234	−0.069	0.945
Income	0.195	0.148	1.313	0.189
Production satisfaction	0.081	0.311	0.261	0.189
Education	0.345	0.160	2.163	0.031*
Age	−0.034	0.016	−2.113	0.035*
Farm type (dairy)	−0.783	0.662	−1.182	0.237
Farm type (LFA)	−0.989	0.479	−2.065	0.039*
Farm type (lowland)	−1.439	0.494	−2.913	0.004**
Farm type (mixed)	−0.015	0.648	−0.224	0.823
Farm type (GC)	−1.364	0.777	−1.755	0.079

3.2.3. Enabling factor

Facilitating conditions*

Once a farmer or adviser decides that they want to use a particular decision support tool, there is a further question of whether they actually *can* use it. For this factor, a range of themes were identified including a mismatch between tool and end user workflow, poor internet access and phone signal, and compatibility with existing systems.

Firstly, to be used regularly DST should fit within the workflow of end users. Although advisers did sometimes make decisions in the field, they were more likely to be office-based. Whilst some of the larger arable farms included office-based staff, many others (particularly livestock) had to make snap decisions in a field or on a hillside.

“When it's daylight you've got to get out there and be doing things... I'm more or less a one man band, so you know your time is very limited these days to use these things.”

(LFA farmer, Conwy, 20006).

The practicalities of using DST therefore varies between settings. It is much easier to use software, apps, or paper in an office environment, but use of DST is more difficult out in the field. For example, one adviser said that “out in the field, my iPhone isn't waterproof...[so] I don't really tend to use it much in the field” (Arable adviser, Wensum, 6). Whilst advisers were better able to use DST when they got home, many farmers commented that it was difficult to overcome the mismatch between the process of using DST and their workflow.

Poor internet and phone signal was also a significant factor restricting use of DST. Both farmers and advisers found mobile phone signal to be “a real issue” (Arable adviser, Wensum, 8). Many felt that the rural community had been “left out in the dry” with “diabolical” signal forcing them to rely on “baked bean tins and string” (Arable farmer, Wensum, 52039). For example, a farmer described how he had tried to use a piece of software in field. However, as a result of the “pathetic” download speeds, he just got “fed up with it” as he needed “instantaneous” answers (Arable farmer, Wensum, 52039).

Lastly, compatibility with existing technology was a problem. Two advisers, in particular, wanted to use a range of decision-making mobile apps, but found that they could not do so. The following extract from one interview demonstrates this shared point:

“I run a Windows phone. And there are very, very few applications I can use. Blackberry are the same. So it's either got to be an Android, or an iPhone. Those are the two phones that seem to take the majority of applications. But in the agriculture industry we use a wide variety of different phones.”

(Arable adviser, Wensum, 2).

Therefore, the crucial step of getting farmers and advisers interested in using a decision support tool is important, but not adequate in itself to facilitate use. Instead, DST should be practically useable once an end user decides to trial one.

3.2.4. Driving factors

Driving factors were useful in encouraging farmers and advisers to use specific DST, even in the midst of failures in terms of user-friendliness or performance (see [Section 3.3](#)).

*Compliance**

A decision support tool was likely to be used if it could help a farmer or adviser to satisfy legislative (or market) requirements. Farmers are required to adhere to various pieces of legislation: for example, there are limits on fertiliser application, and requirement to provide records of animal health treatments and stock movements. Several interviewees suggested that software recording programmes had been purchased to meet compliance. A livestock farmer, for example, described how “we're going to have to record all our movements...so we've got to start [using recording programmes] sometime.” (LFA farmer, Conwy, 20017). Referring to compliance-led software tools, farmers valued the point that inspectors seemed to “like the fact that farmers are using” (Arable farmer, Wensum, 51007). Whilst some interviewees wondered whether the use of such tools “made you any better”, all agreed that they were “bloody good for traceability” (Arable farmer, Wensum, 51084). The importance of tools that satisfy compliance is furthered in [Section 3.3](#).

Level of marketing

To reach the stage of intending to use a tool, the end user has to know that it exists. Larger manufacturers are often able to provide free trials and market their products more widely, and this affects uptake.

One farmer suggested that he got into a software package because he “was sent a CD with it on through the post” (Arable farmer, Wensum, 51007), whilst advisers were more likely to be using a tool if it had “been promoted very well” (Livestock adviser, Conwy, 8). Consequently, therefore, specific tools were not used if end users were not aware of it. When asked about potentially useful software packages or apps, one farmer reported that he was “not aware that there is anything about to help” (LFA farmer, Taw, 10022). Thus, level of marketing is an important determinant of uptake, and this point is furthered in [Section 3.3](#).

Manufacturer presentations

In their workshop presentations, decision support tool manufacturers mentioned a number of specific factors that they had considered when designing it for a farmer or adviser. The most common factors mentioned included performance, ease of use, trust, compliance, and cost. Thus, the manufacturers were most focused on designing sophisticated tools with user-friendly interfaces (which sometimes also helped farmers to meet compliance), whilst building trust. Some of the other important determinants of uptake mentioned by farmers, such as the value of peer-to-peer and farmer-adviser knowledge exchange were seldom mentioned (see [Appendix 4](#)).

3.3. Relative importance of factors

It is not possible to comment quantitatively on the relative importance of each factor, but the starred factors were mentioned most often (performance, ease of use, peer recommendation cost, habit, age, IT education, facilitating conditions, compliance). In terms of the most important factors affecting uptake and use of a decision support tool, the two driving factors are particularly influential.

Firstly, level of marketing is a key determinant of tool uptake. The long, yet incomprehensive, list of available DST illustrates the wide range of options for farmers and advisers. Yet, it is likely that end users were not aware of the vast majority of tools on the list. Secondly, tools that helped with compliance seemed to outweigh many other factors. To illustrate this, a case study describing why a specific software package was used for nutrient application is useful.

This particular software package was widely used by farmers and advisers across the arable and lowland livestock enterprises. At first this finding was curious because the tool was criticised for not being user-friendly:

“I just thought it was unnecessarily complicated for what I needed”.
(Arable adviser, Wensum, 14).

“It's a beast...Some people might get on with it. I haven't met many that have”.
(Livestock adviser, Taw, 2).

“Sometimes I could chuck it out the window”.
(Livestock adviser, Taw, 5).

It is therefore interesting to ask why the tool was used despite failing on user-friendliness, which appeared to be a key determinant of uptake from the research. By looking more closely at further responses from the same users, it is clear that its ability to meet compliance outweighed user-friendliness. Firstly, the user who considered “chucking it out of the window” argued that “the reason we use it...is if you have an inspection and you've got it...it takes a lot of weight off” (Livestock adviser, Taw, 5). A second adviser who did not “get on with it” stated that it is the “only bit of information out there to do your NPK records on” (Livestock adviser, Taw, 2). Similar responses were obtained from the other users who criticised the software tool. Therefore, without being able to argue which of the factors is most important in determining uptake

and use, the ability of DST to help users satisfy legislative (or market) requirements is clearly influential.

4. Discussion

The fifteen factors identified in this research provide useful insights into the characteristics on an effective decision support tool. In many ways, the results are similar to studies conducted elsewhere. For example, *Alvarez and Nuthall (2006)* undertook research in New Zealand and Uruguay into decision support tool uptake and found various attributes important to uptake; these included farmer objectives, personality, education, skills, learning style and the size of business. Research in Australia has highlighted the importance of perceived usefulness, ease of use, fit to task/workflow, profitability, credibility, relevance to individual farms, updated information, and level of user-knowledge (*Kerr, 2004; McCown, 2002*). Indeed, *Hochman and Carberry (2011)* argue that there is an emerging consensus about the desirable characteristics of an effective decision support tool. The factors found to be most influential in their review included a plan for delivery after the initial funding period, involvement of users, appropriate education, the need to satisfy user needs, a strong evidence-base, and good marketing. And yet despite *Hochman and Carberry's (2011)* statement of an emerging consensus, other authors have still described the problem of low uptake as an 'enigma' (*McCown, 2012*).

In response to McCown's comment, the research conducted here in a UK context would seem to support *Hochman and Carberry's (2011)* view that a consensus exists. The results are also similar in nature to key factors identified by *Venkatesh et al. (2012)* in the 'Unified Theory of Acceptance and Use of Technology (2)'. Although our theory incorporates specific factors related to agriculture, the similarity with research conducted in other disciplines³ suggests that designers of agricultural DST could learn from expertise elsewhere. The key characteristics of a successful decision support tool appear to be well-known, and the findings of this research add further weight to existing evidence. Perhaps the most concerning element of this research relates to the lack of incorporation of this knowledge into tool design. Despite several commensurate studies in agriculture that have identified similar factors, this research has found continuing low uptake. Of course, it is important to note that software-based and app-based DST can only ever be part of the solution to evidence-based decision-making on-farm. Such tools will simply not be to every user's tastes and therefore other options are needed in these cases. However, of greater concern are the tools in circulation that fail on many factors in *Fig. 2*. The interview data illustrates that users have tried many different DST, but found problems of usability, lack of relevance, high cost, and poor performance, amongst others. Thus, it seems necessary to strengthen calls for better design and delivery plans to avoid the implementation problem.

Reflecting briefly on the methods used for this research, it would be useful to undertake similar research in horticultural, pig, and poultry enterprises. Similarly important decisions are being made in these enterprises and there may be a place for further use of decision support tools. We considered the response rate to the baseline survey to be fairly good, certainly as compared to many other agricultural projects. There is little to suggest that self-selection bias was prominent, in other words that forward-thinking farmers with a personal interest in Defra's Sustainable Intensification platform would be more likely to respond. In fact, the survey found low knowledge of sustainable intensification and use of decision support tools. Hence, we consider that the sample was adequate for the purposes of this research.

³ The Unified Theory of Acceptance and Use of Technology (UTAUT) incorporated previous theories including the Technology Acceptance Model. These previous theories had been developed using a variety of different case studies. For example, *Williams et al. (2015)* found that the original article on UTAUT (*Venkatesh et al., 2003*) was cited on 5000 occasions in subjects including Hospital Information Systems, Tax Payment Systems and Mobile Technology amongst several others. *Venkatesh et al. (2012)* specifically used the theory to investigate mobile technology uptake.

4.1. Future directions for the design and delivery of DST

In light of the findings, a number of suggestions can be made to guide the future design and delivery of DST. Firstly, designers could use the fifteen factors identified in this research as a checklist alongside which to measure the quality of new tools. This checklist is presented in *Box 1* with a series of sample questions that designers could ask themselves throughout projects.

Instead of focusing merely on designing sophisticated tools that are easy to use, some of the other important, but seldom highlighted, factors could be taken into account. Foremost amongst these, the ability to help users to satisfy legislative requirements via DST will encourage uptake, whilst delivery on the ground can be enhanced by working with existing trusted local networks. It may also be fruitful to target software and app-based systems at younger audiences with larger farms in the first instance. Then, once established amongst this group, manufacturers could work with government and the wider farming community to improve IT education (which may help in breaking embedded habits), as well as improving rural connectivity.

The findings also raise a tension between taking a 'carrot' or 'stick' approach to the use of DST. Quite clearly, farmers and advisers will use a decision support tool if they are required to by legislation or market requirements, such as complying with a quality assurance schemes. Thus, forcing them to use a specific tool by law would be the quickest route to uptake. Yet, such methods are draconian and risk alienating a set of end users already feeling the strain of administration and adhering to regulations. An alternative is to incentivise use, perhaps through market mechanisms, by showing how tools can add value to a business (e.g. saving time and making/saving money), or through financial incentives, such as grants or subsidies to help farmers recuperate the costs of purchasing DST. The results illustrated that this mechanism had been successful in encouraging some farmers, particularly upland livestock farmers with limited cashflow, to invest in such systems. However, the results illustrated that a large proportion of those farmers who

Box 1

Checklist for good design of decision support tools.

- 1. Performance** – does the tool perform a useful function and work well?
- 2. Ease of use** – is the user interface easy to navigate?
- 3. Peer recommendation** – how can we encourage peer-to-peer knowledge exchange?
- 4. Trust** – is the tool evidence-based and do we have the trust of users?
- 5. Cost** – is there a cost-benefit or is the initial cost too high?
- 6. Habit** – does the tool match closely with existing habits of farmers?
- 7. Relevance to user** – can the tool say something useful about individual farms?
- 8. Farmer-adviser compatibility** – could the tool be targeted at advisers to encourage client uptake?
- 9. Age** – does the tool match the skills and habits of different age groups?
- 10. Scale of business** – how far is the tool applicable to all scales of farming?
- 11. Farming type** – how far is the tool useful for different farming enterprises?
- 12. IT education** – does the tool require good IT skills to use?
- 13. Facilitating conditions** – can the tool be used effectively? i.e. is there internet access? Does it fit farmer workflows? Is there compatibility with use of existing devices?
- 14. Compliance** – how can the tool help users to satisfy legislative and market requirements?
- 15. Level of marketing** – how do we let users know about our tool?

had purchased DST with 80% or 100% grants were not actually using them regularly. Therefore, it raises the question as to whether the grant scheme was a cost-effective use of resources. Certainly, more work is needed to strike the right balance on this spectrum.

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