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RESEARCH ARTICLE

Willingness to pay for smartphone apps facilitating sustainable crop protection

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Abstract
By providing additional information and simulating results, decision support tools are one of the methods to enhance a farmer's decision-making process in order to achieve more sustainable practices. With the latest developments in smartphone technology, new possibilities to integrate decision support tools into the daily work process have been emerging and smartphone apps related to crop protection have been developed. However, little is known about the utilization of smartphones by farmers in general, and specifically with regard to crop protection. In order to gather first insights into the factors that could affect the decision of farmers to integrate smartphones and crop protection-related apps in particular, into their work process, we conducted an online survey with 174 technologically experienced German farmers in 2017. We gained insights about the current use of smartphones from the surveyed German farmers, explored which topics farmers perceive as useful in the form of an app for crop protection, and which factors influence the willingness to pay for these apps. Our results show that 93% of the respondents use smartphones for agricultural purposes. Weather forecasts, tools to identify pests, diseases and weeds, as well as related forecasts are perceived as useful by the majority of respondents. Eighty-two percent of the respondents are generally willing to pay for crop protection apps. Using a probit model, we found that the farmer's age, farm size, knowledge about specific crop protection apps, potential for cost reduction, and potential to reduce negative environmental effects have an influence on the general willingness to pay. Overall, this is the first study to explore factors influencing the willingness to pay for crop protection apps and assess which types of apps are perceived as useful by technologically experienced German farmers.

Keywords Smartphone · Crop protection apps · Willingness to pay · Perceived usefulness · Probit model · German farmers

1 Introduction

Increasing the sustainability of production and ensuring the competitiveness of individual farms are major challenges facing agriculture today. The agricultural sector has to deal with partially conflicting objectives, such as extending production in order to provide a global food supply to meet the growing demand, while simultaneously decreasing negative environmental effects (EU SCAR 2012). The individual farmer's decisions are inevitably linked to sustainable agricultural intensification, having either positive or negative effects on sustainability (Matthews et al. 2008; Lindblom et al. 2017). With regard to crop protection, mandatory regulations for integrated pest management have been implemented by the European Union in order to reduce negative external effects and promote sustainability of agriculture (EU 2009). Some European countries additionally have a tax on pesticide use as an effort to reduce negative environmental effects (e.g., Lefebvre et al. 2015). Besides an increasing body of legal regulations as a form of public intervention, possibilities to support a farmer's decision-making process are increasingly relevant. The transfer of agronomic knowledge about sustainable practices, in the form of applicable decision support, is one means of bringing about more sustainable agricultural intensification (Struik and Kuyper 2017).

As an ongoing process, the digitalization of agriculture inter alia has manifested a substantially increased number of available decision support tools (DST) for farmers and precision farming techniques (e.g., Xin et al. 2015). A DST can be described as a software-based system which allows farmers to

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gather additional information for making decisions under uncertain conditions (Shtienberg 2013). The extent and complexity of a DST can thereby vary from a simple source of information to complex simulation models integrating farm- or site-specific data (e.g., Rose et al. 2016). In integrated pest management, selecting the best pest management strategies depends on a number of factors, for example early diagnosis and prediction of pest development. DST can play an essential role in simulating disease evolution and are able to deliver results in a timely manner (Damos 2015).

With the most recent developments in information technology, especially smartphones with Internet access, new possibilities for the implementation and use of DST have emerged. In comparison to computer-based DST, smartphones and related apps have the major advantages of allowing access to information on demand and flexibility of usage. The mobility of smartphones, in particular, is well-suited to the nature of the daily operational activities in agriculture. The features and complexity of available apps vary considerably. With regard to crop protection, some apps substitute and combine several previously used information sources in a single device (Fig. 1). Other apps can complement existing information networks by incorporating farm-specific data in simulation models and thus directly enhance decision making under uncertain conditions.

Although today's smartphones and apps offer numerous benefits and can promote sustainability, the adoption of mobile technology in agriculture lags behind other sectors (e.g., Xin et al. 2015). Only a limited number of studies have focused on the adoption of smartphones by farmers and the use of apps within Europe (e.g., Dehnen-Schmutz et al. 2016; Hoffmann et al. 2013). While it has been acknowledged that proving the financial value of a DST is an important part of the development process (e.g., Rose et al. 2018), research on the farmer's willingness to pay (WTP) for these DST does not exist. Without focusing on the potential value a DST has for a farmer, the uptake of new technology-based DST will remain low (Evans et al. 2017).

Fig. 1 Smartphone apps can, for example, include weather information, calculators for spraying rates, and tools to identify pests and diseases. Shown here are some tools which can already be replaced by using smartphone apps

The price range for crop protection apps currently available in stores is substantial. While several free apps are available, the number of paid apps is increasing. The price of a DST and precision farming technologies has been named as one of the reasons why adoption has been below expected levels (e.g., Matthews et al. 2008). Consequently, it is reasonable to evaluate which factors have an influence on the WTP for app-based DST to identify possible barriers to adoption. Moreover, it is plausible that the more complex a DST becomes, the higher the development and maintenance costs. If farmers are not willing to pay to use these tools, there is no incentive for independent developers to improve and enhance existing tools. It is the aim of this study to gain a first insight into the factors that influence the general WTP for crop protection apps by German farmers who are experienced in the use of information technology. Furthermore, the perceived usefulness of various crop protection-related topics by those farmers is evaluated, since apps that are not perceived as useful are unlikely to be adopted, irrespective of the price. In addition, information about the current utilization of smartphones by the surveyed German farmers is presented. This study is the first to explore factors influencing farmers' general WTP for crop protection apps. In addition, crop protection-related topics which are perceived as useful in the form of a smartphone app are assessed.

2 Material and methods

2.1 Research hypotheses

Dentzmann (2018) notes that a large variety of influencing factors related to technology adoption in agriculture has been investigated in a number of studies. These studies provide a diverse set of factors that might influence adoption decisions to varying degrees. Rather than contradicting each other, these factors emphasize different magnitudes of impact on adoption in different contexts. Hence, among others, motivational factors are used to explain adoption decisions. In case of crop protection, altruistic and egoistic motivational factors should be considered, since side effects of crop protection are notable beyond the scope of the single farm. Studies focusing on the adoption of technology and DST also usually consider factors related to the farm and farmer (e.g., Batte 2005; Briggeman and Whitacre 2010; Rose et al. 2016). Therefore, hypotheses related to farm and farmer characteristics are additionally derived from the literature, with particular focus on those factors which are likely to be relevant in the context of a WTP for crop protection apps.

2.1.1 Motivational factors

Rose et al. (2016) reported that the performance expectancy of a decision support system, i.e., the financial benefit, influences the adoption decision. Likewise, Spaulding et al. (2015) found that performance outcome expectations positively influence the continued usage of mobile devices. Since a positive performance outcome of an app, for instance an app that calculates exact spraying rates, is assumed to ultimately result in some form of cost reduction, it can be assumed that the willingness to pay for an app is positively correlated with the expectations of cost reduction. Therefore, we assume that the WTP for crop protection-related apps increases with the perceived potential to reduce costs and derive the following hypothesis:

> H1: Perceived potential of cost reduction has a positive influence on the WTP for crop protection apps

In contrast to cost reduction, reducing negative externalities and increasing the sustainability of the production process are altruistic motivational factors from the farmer's perspective. In order to achieve these objectives of integrated pest management, a number of regulations, including record-keeping obligations, have been implemented. In this context, Rose et al. (2016) reported that compliance with regulations is one of the factors which determines the adoption of a DST. Matthews et al. (2008) found that the majority of respondents prioritized abilities related to the sustainability of production as features which are viewed as beneficial for a DST. Furthermore, a potential intrinsic motivation to protect the environment might positively influence the WTP. As Spash et al. (2009) stressed, environmental attitudes can be relevant for management decisions. They found that simply the expectation of an upward trend in biodiversity is enough to increase the WTP for measures to increase biodiversity. Therefore, we assume that the potential to reduce negative environmental effects by using an app has a positive influence on the WTP for such an app, and the following hypothesis is derived:

> H2: Perceived potential to reduce negative environment effects has a positive influence on the WTP for crop protection apps

2.1.2 Farmer and farm characteristics

Farmers are the main target group and consumers of crop protection apps. Hence, socio-demographic factors are assumed to have an influence on the general adoption decision and consequently also on the general WTP for crop protection apps. The results of Batte (2005) indicate that younger farmers are more likely to adopt computers for business purposes. Similarly, Briggeman and Whitacre (2010) found that Internet adoption decreases with increasing age. Rose et al. (2016) confirmed a negative relationship between farmer age and the use of information and communication technology-supported decision support systems. Furthermore, Dehnen-Schmutz et al. (2016) concluded that smartphone adoption is higher among younger farmers. Therefore, we assume that the age of the farmer also has a negative influence on the WTP for apps and derive the following hypothesis:

> H3a: Increasing age has a negative influence on the WTP for crop protection apps

Briggeman and Whitacre (2010) found that a college degree increases the likelihood of Internet adoption by 20%. In line with this, Batte (2005) reported that education has a statistically significant effect on computer adoption. Mishra and Park (2005) found that education has a statistically significant effect on the number of different Internet uses by the farmer. They argued that a higher education level is associated with the farmer being able to identify the value of additional information sources. Since education has a positive effect on the decision to adopt computers and the Internet, we assume that the WTP for crop protection apps is also positively influenced by education. Accordingly, the following hypothesis is derived:

> H3b: An agricultural university degree has a positive influence on the WTP for crop protection apps

Since smartphone apps are a relatively new technological development and the adoption in the agricultural sector has lagged behind other industries (e.g., Xin et al. 2015), it is questionable whether farmers are aware of the existence of specific crop protection apps. Dehnen-Schmutz et al. (2016) reported insufficient time to find suitable apps as the most often cited reason farmers give for not using apps. Reichardt et al. (2009) also emphasize that knowledge about precision farming techniques is a key factor for its adoption. In a similar case, Rose et al. (2016) found that habit is a significant factor affecting the use of a DST. Hence, the knowledge concerning crop protection apps is also a precondition for changing the farmer's habit towards the integration of a DST into his daily business. Previous exposure to specific apps also enables farmers to better assess the utility they could gain from using an app. Therefore, it is reasonable that knowledge about crop protection apps positively influences the WTP and we derive the following hypothesis:

> H3c: Prior knowledge of specific crop protection apps has a positive influence on the WTP for crop protection apps

Besides the characteristics of the farmer, as the decision-maker on the farm, the properties of the farm itself can play a role for the WTP for crop protection apps. Briggeman and

Whitacre (2010) found that Internet adoption increases with increasing gross farm sales. Mishra and Park (2005) reasoned that a larger farm faces more complex decisions and that information accordingly has a higher value. They reported that the farm size, measured as the value of commodities sold, has a statistically significant positive effect on the number of Internet uses. Following the general concept of economies of scale, it can be assumed that larger farms are more likely to have a positive WTP compared to smaller farms. To evaluate the WTP for crop protection apps, the cultivated area is assumed to be an appropriate indicator for the farm size. In addition, the pricing schemes of some apps are actually dependent on the farm size in hectares. Accordingly, the following hypothesis is derived:

> H4a: Larger farm size has a positive influence on the WTP for crop protection apps

Mishra and Park (2005) found that diversification of production on the farm has a statistically significant positive effect on the number of Internet uses. The authors argued that more diversified farms also have a diversified and expanded need for information regarding the business. This argument is also applicable in terms of the use and WTP for crop protection apps. In addition, it is reasonable that farmers who are specialized in crop production, rather than undertaking both crop and livestock production, have more specialized experience and knowledge, which would make an app less useful and accordingly would negatively influence the WTP. Therefore, it is expected that diversification of the farm has a positive effect on the WTP for crop protection apps and the following hypothesis is derived:

> H4b: Higher production diversification has a positive influence on the WTP for crop protection apps

2.2 Survey design

To test the derived hypotheses, an online survey with German farmers was conducted. The link was distributed via e-mail to a mailing list consisting of farmers who have previously participated in thematically different surveys conducted at the University and over social media. The survey was based on a structured questionnaire with close-ended questions and had four parts. The first part consisted of questions regarding smartphone ownership and usage. In the second part, questions regarding specific topics related to crop protection apps were included. As many authors pointed out, it is crucial to involve farmers in the development process of DST to ensure that the farmers' demands are met and that these tools are applicable (e.g., Matthews et al. 2008; Janssen et al. 2017; Evans et al. 2017; Rose et al. 2018). Therefore, the farmers were asked which of the presented topics they perceive as being useful in the form of an app to optimize their crop protection strategies. In accordance with the (extended) Unified Theory of Acceptance and Use of Technology, performance expectancy, i.e., to which degree using a technology will provide benefits, is also one of the major factors determining if a technology will be adopted (Venkatesh et al. 2012). To avoid potential bias that could be created by referring to specific apps that are available but which might not be known to all respondents (Dehnen-Schmutz et al. 2016) and to capture the general trends, we chose to ask about potential topics rather than about specific apps.

The third part included the questions regarding the motivational factors derived by the hypotheses as well as the question about the WTP. The variables for the perceived potential of cost reduction and the perceived potential to make crop protection more environmentally friendly were measured on a 5-point Likert-scale, ranging from "1 = fully incorrect" up to "5 = fully correct". In order to gain first insights into the general WTP for crop protection apps, the respondents were asked if they are generally willing to pay a yearly fee for smartphone apps related to crop protection. As pricing schemes as well as functions vary considerably for apps currently available in Germany, the WTP was collected in a discrete form (yes or no decision) instead of concrete values. The questionnaire ended with questions about the sociodemographic characteristics of the farmer and questions regarding the farm business.

2.3 Approach to data analysis

In order to identify the effects of the motivational factors as well as the farmer and farm characteristics on the WTP for crop protection apps, a probit model was estimated (e.g., Greene 2007). The dependent variable was defined as 0 = not willing to pay and 1 = willing to pay. The variables described by the hypotheses were included as explanatory variables.

Since the WTP is defined as a binary response, it can be classified as a limited dependent variable. The outcome of a discrete choice, in this case a positive WTP or WTP equal to zero, can be viewed as a reflection of an underlying regression (Greene 2007). Accordingly, the difference between a positive WTP and WTP equal to zero is expected to depend upon the set of explanatory factors derived in the hypotheses (see 2.1) and additional unobserved factors captured by a constant and the error term. The latent index function for the WTP is presented as follows:

$$y^* = \boldsymbol{x}'\boldsymbol{\beta} + \varepsilon \qquad \varepsilon \sim N(0,1) \tag{1}$$

where y^* is the unobservable latent variable (in our case the WTP), $\boldsymbol{\beta}$ is the vector of estimated coefficients, $\boldsymbol{x}$ is the vector of included explanatory variables, and ε is the error term, which is assumed to follow the standard normal distribution.

As the WTP is coded as a binary variable, the observation can be presented as:

$$y = \begin{cases} 1 \; if \; WTP > 0 \\ 0 \; if \; WTP = 0 \end{cases} \quad (2)$$

Based on the assumption that the error term follows the standard normal distribution, as indicated in Eq. (1), the probit model was chosen to estimate the effects of the explanatory variables on the WTP. Consequently, we specified the following model:

$$\begin{aligned} WTP_i = \beta_0 + \beta_1 CostReduction_i + \beta_2 Environment_i \\ +\beta_3 Age_i + \beta_4 AgriUni_i + \beta_5 KnowApps_i \\ +\beta_6 Farmsize_i + \beta_7 Livestock_i + \varepsilon_i \end{aligned} \quad (3)$$

where i represents the individual respondent and ε_i is assumed to be a random error term. To verify the model specification, a logit model, which is based on a logistic distribution of the error term, was estimated additionally. The explanatory variables included in Eq. (3) are in accordance with the derived hypotheses and their descriptive results are shown in Table 1. The probit model, including the marginal effects, was estimated using STATA 15.

3 Results and discussion

3.1 Descriptive results

The survey was conducted online in August 2017 in Germany. The link was distributed via e-mail and over social media. A total of 194 farmers participated in the online survey and 174 completed the questionnaire. For the statistical analysis, only the completed questionnaires were considered ($N = 174$). With an average age of 35.65 years (ranging from 17 to 61), the surveyed farmers were relatively young compared to the population of German farmers, of whom more than one third is older than 55 years (DBV 2016). Almost one third of respondents (31.03%) held an agricultural university degree. Therefore, the sample of surveyed German farmers comprised relatively young and well-educated farmers which are not representative for Germany.

A total of 60.92% (106) of the farmers were classified as an owner or manager of the farm, 31.03% as farm successors, and 8.05% as employees. The farm size ranged from 1 to 2000 ha, with an overall mean of 219.21 ha (standard deviation 338.46). About half of the farms (50.57%) cultivated less than 100 ha. A total of 123 farmers indicated that their farms were operated on a full-time basis. A total of 56.32% of the farms were engaged in livestock farming in addition to crop cultivation.

All of the 174 participants owned a smartphone, and 163 (93.68%) specified using the smartphone for agricultural purposes. In comparison to prior studies (e.g., Hoffmann et al. 2013), smartphone adoption and usage for agricultural purposes among farmers have increased. Dehnen-Schmutz et al. (2016) also found a high utilization rate of 89% and reasoned that due to the online recruitment procedure, the participants were likely to be more technologically informed. In addition, it is reasonable that the adoption rate in the described sample is higher, since the survey was conducted more recently. The majority of smartphones had an Android (56.90%) or an iOS (39.66%) operating system. On average, the farmers had 5.26 years of smartphone experience, implying that they are familiar with the use of smartphone technology.

Table 1 Descriptive results for variables included in the probit model (N = 174)

Variable	Total N = 174	Total % N
CostReduction		
Fully incorrect	9	5.17%
Partially incorrect	55	31.61%
Partially incorrect/correct	49	28.16%
Partially correct	50	28.74%
Fully correct	11	6.32%
Environment		
Fully incorrect	4	2.3%
Partially incorrect	29	16.67%
Partially incorrect/correct	66	37.93%
Partially correct	68	39.08%
Fully correct	7	4.02%
Age (in years)		
<25	30	17.24%
25-34	66	37.93%
35-44	36	20.69%
45-54	22	12.64%
>54	20	11.49%
AgriUni (agricultural university degree)		
Yes	54	31.03%
No	120	68.97%
KnowApps (knowledge of crop protection apps)		
Yes	134	77.01%
No	40	22.99%
Farmsize (in ha)		
< 100	88	50.57%
100 – 199	35	20.11%
200 – 299	16	9.20%
300 – 499	11	6.32%
> 499	24	13.79%
Livestock (in addition to crop production)		
Yes	98	56.32%
No	76	43.68%

Farmers were asked if they were willing to pay a yearly fee for a crop protection app which included all of the functions they perceive as useful. Overall, 82.76% (144) of the farmers indicated that they are willing to pay for a crop protection app. These results are similar to the results of Hoffmann et al. (2013), who found that 91% of the German farmers who had the intention to buy a mobile device also had a positive WTP for apps. However, our results show that only 32.18% of the respondents already used paid apps for any agricultural purpose. This can partially be explained by the large number of free apps that are currently available for various purposes, although it has to be considered that most of these free apps tend to be information sources rather than complex simulation models. In addition, many of the free apps related to crop protection are provided by the big manufacturers of crop protection products and, as such, might be biased. Furthermore, this difference between WTP and payment in reality implies that the currently available apps for crop protection and other agricultural purposes might not cover subject matter which a farmer perceives to be worth paying money for. This assumption is supported by various studies regarding DST which conclude that farmers need to be involved in the development of these tools in order to ensure the tools fulfill the farmers' requirements (e.g., Matthews et al. 2008; Janssen et al. 2017; Lindblom et al. 2017). Moreover, 22.99% of the technologically experienced German farmers stated that they did not know of any specific crop protection apps, which also means these farmers are not fully aware of how a smartphone-based DST could improve their crop protection. The farmers were also asked if they would be more likely to use an app which hypothetically was certified by an independent government agency. A total of 109 of the respondents (62.64%) affirmed that they would rather use a certified app. A certification scheme for agricultural apps currently does not exist; however, this result implies that a certification scheme could be beneficial for the adoption of crop protection apps.

For perceived potential of cost reduction, the mean was 2.99 on the Likert-scale, with a standard deviation of 1.03. This implies that farmers perceive the potential of cost reduction as "partially correct/partially incorrect". The potential to enhance the environmental friendliness of crop protection was given an average of 3.26 on the Likert-scale (standard deviation 0.86), trending slightly towards "partially correct". This result indicates that smartphone-experienced German farmers value the potential of smartphone apps to reduce negative external effects and hence increase sustainability of production as slightly higher, on average, than the potential to reduce costs. These results might seem contradictory to a certain extent, since a partial interrelationship between cost reduction and reduction of negative external effects can be assumed. However, an app that, for instance, helps the farmer choose a crop protection product that is climate- or site-specific, does not inevitably lead to a cost reduction. Another example would be an app that provides the farmer with specific weather information, including relative humidity and wind intensity. Such an app can help enhance the application of crop protection products and reduce drift, consequently decreasing negative environmental effects while not necessarily reducing the costs, at least not in the short run.

3.2 Perceived usefulness of crop protection apps

To identify which types of apps are viewed as beneficial and hence are more likely to be used, the perceived usefulness of various presented topics was evaluated (Fig. 2). Of all the topics, weather forecasts were considered to be useful as an app by the greatest percentage of farmers (85.06%). This result is in accordance with the results of Dehnen-Schmutz et al. (2016), who found that weather apps were the type of app most often used by British farmers. Mobile access to weather forecasts on demand is an advantage of smartphones and other digital mobile devices compared to other sources of weather information, like the news.

Identification of pests, diseases, and weeds as well as related forecasts are predominantly perceived as useful. These topics are directly related to the optimized use of crop protection products. A total of 77.60% of the farmers deemed recommendations of manufacturers of crop protection products to be not useful. One reason for the low perceived usefulness could be that farmers view apps released by manufacturers as biased. This is in line with Rose et al. (2018) who emphasize that trust in a DST is a key factor relating to its implementation. Only 1.15% of the respondents indicated that no crop protection app would be useful. This implies that most of the farmers view smartphone apps as beneficial in their work environment and that apps can contribute to improving integrated pest management in terms of sustainability on the farm level.

3.3 Willingness to pay for crop protection apps

A binomial probit model was estimated in accordance with Eq. (3) to test the derived hypotheses. The results are presented in Table 2. The likelihood ratio test of the model is statistically significant ($\text{Chi}^2(7) = 31.64$ and $p = 0.000$), failing to support the null hypothesis that all coefficients are zero. To evaluate the goodness-of-fit of the model, the Hosmer-Lemeshow Chi-squared test was performed. With a p value equal to 0.2183 ($\text{Chi}^2(8) = 10.72$), the null hypothesis, in which expected and observed outcomes are consistent, is supported. A classification test revealed that the model correctly classifies 86.21% of the responses. The calculated pseudo R^2 value of 0.1978 also indicates a good explanatory power of the presented model. To test for multicollinearity, the mean variance inflation factor was calculated. A value greater than 10 would imply multicollinearity between the explanatory variables (Curto and Pinto 2011). With a mean variance inflation

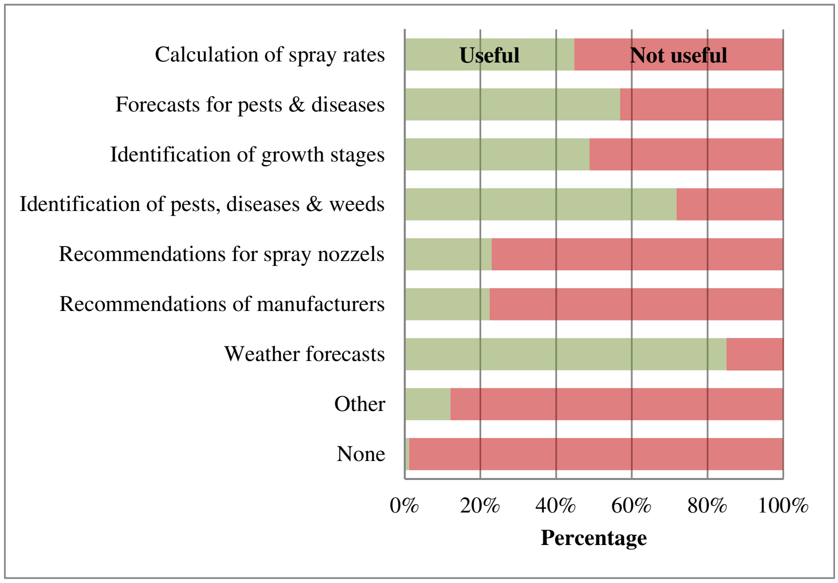

Fig. 2 Responses ($N = 174$) regarding the perceived usefulness of apps related to various crop protection topics. Responses were recorded as a dummy variable: 0 (=not useful) and 1 (=useful). Weather forecasts are predominantly perceived as useful. Only two respondents (1.15%) indicated that none of the apps would be useful

factor of 1.15 (ranging from 1.01 to 1.33) for the variables included in the model, it is assumed that multicollinearity between the explanatory variables is not present and hence the model is valid. Furthermore, a logit model for the same variables was estimated to account for a different distribution of the error term. The results are very similar; however, the Hosmer-Lemeshow test for the logit model ($Chi^2(8) = 15.92$ $p = 0.0453$) suggests that a probit model is more appropriate for the data analysis.

3.3.1 Motivational factors

The marginal effect for "CostReduction" indicates that a one unit increase in the perceived potential of cost reduction increases the likelihood of a positive WTP on average by 5.48%, ceteris paribus. Accordingly, H1 is supported. This result indicates that the technologically experienced German farmers value the utility of apps to reduce costs associated with crop protection at the farm level. This result is in accordance with Evans et al. (2017) and Rose et al. (2018) who emphasize that proving the financial benefits resulting from the use of a DST is important to increase the uptake of DST.

The variable "Environment" is statistically significant at the 1% level, implying that an additional unit of the perceived potential to enhance environmental protection increases the likelihood of a positive WTP on average by 8.83%, ceteris paribus. This result is similar to what Rose et al. (2016) found, i.e., that compliance with regulations is a factor which determines whether a farmer chooses to use a decision support system or not. In addition, it is reasonable that farmers are also intrinsically motivated to reduce negative environmental effects, which can partly explain the increasing likelihood of a positive WTP with increasing perceived potential to enhance environmental protection. Furthermore, this result supports

Table 2 Results of the binomial probit model of the general WTP for crop protection apps. Marginal effects are calculated as average marginal effects

WTP	Coefficient	Standard error	Marginal effects	Standard error	*p* values
Constant	– 0.9662	0.6735			
CostReduction	0.2649	0.1453	0.0548	0.0294	0.062*
Environment	0.4271	0.1675	0.0883	0.0335	0.008***
Age	– 0.0195	0.0112	– 0.0040	0.0023	0.075*
AgriUni	– 0.4800	0.2843	– 0.0992	0.0577	0.086*
KnowApps	0.6392	0.2705	0.1321	0.0541	0.015**
Farmsize	0.0013	0.0007	0.0003	0.0001	0.042**
Livestock	0.0800	0.2670	0.0165	0.0551	0.764
Log likelihood	– 64.1644				
Pseudo R^2	0.1978				
N	174				

Asterisks indicate different levels of significance (***$p < 0.01$, **$p < 0.05$, *$p < 0.10$)

the assumption that the WTP for environmental measures is not solely dependent on economic factors (Spash et al. 2009).

3.3.2 Farmer and farm characteristics

The results of the probit model imply that a 1-year increase of the farmers' age decreases the likelihood for a positive WTP on average by 0.40%, holding all other factors constant. This result is statistically significant at the 10% level and thus the hypothesis that age has a negative influence on the WTP is supported. This result is in accordance with previous studies on the adoption of new technologies by farmers (e.g., Batte 2005; Briggeman and Whitacre 2010). While the average age in the sample is comparatively young and might slightly bias the results, this general trend is plausible, especially considering that technology dependence is going to increase in the future and that farm successors are even more likely to know the benefits of these technologies.

An agricultural university degree has a statistically significant negative effect on the WTP for crop protection apps. Having an agricultural university degree thereby decreases the likelihood of a positive WTP on average by 9.92%, ceteris paribus. Hence, the hypothesis H3b cannot be supported. This result is in contrast to the results of Briggeman and Whitacre (2010) regarding Internet adoption. A possible explanation is that the apps currently available do not provide knowledge which has an additional value for highly educated farmers, i.e., existing apps could be too simple. Therefore, more advanced apps might be required by famers with a stronger educational background in order to elicit a willingness to pay. Gent et al. (2011) also described a learning effect which causes farmers to cease using a DST once they have identified and understood the underlying decision mechanism of the system. This could also be true for more highly educated farmers. Additionally, as more highly educated farmers are more likely to have adopted computers (Batte 2005) and the Internet (Briggeman and Whitacre 2010), they might be more aware of other software-based solutions which can help to improve their crop protection.

Previous knowledge of specific crop protection apps increases the likelihood of a positive WTP by 13.21% on average, holding all other factors constant. Accordingly, H3c is supported at the 5% level of significance. This result is plausible considering that knowledge about specific apps implies that farmers can better assess the utility of apps. Moreover, this positive relationship implies that farmers value the benefits of apps and that knowledge about apps could facilitate adoption. This is especially relevant, since it can be assumed that apps will change over time and new apps will be developed to replace existing ones (Evans et al. 2017). The positive effect of knowledge on the likelihood of a positive WTP can also be used as an indicator that farmers are willing to use smartphone-based DST and change their habits, which has been identified as one of the most challenging factors (Rose et al. 2016).

The variable "Farmsize" is statistically significant at the 5% level, implying that an additional hectare of land increases the likelihood of a positive WTP, ceteris paribus, by 0.03% on average. This positive marginal effect is in accordance with the concept of economies of scale, it also parallels the results of studies on computer and Internet adoption (Mishra and Park 2005; Batte 2005).

The diversification of production on the farm, i.e., crop production combined with livestock farming, has no statistically significant effect on the likelihood of a positive WTP. Consequently, the hypothesis H4b cannot be supported. This implies that specialized farms and diversified farms value the benefits of an app equally. Nonetheless, farms with different production portfolios, also within the group of crop producers, have diversified needs for information, which leads to a need for the availability of different kinds of DST (Evans et al. 2017).

3.4 Relevance of the results

Since our study is based on an online questionnaire, the collected data is biased. Hence, the sample consists of relatively young, well-educated, and technologically experienced farmers and is not representative of German farmers as a whole. This has to be considered for the evaluation of the external validity of our findings. European statistics show that there are many more farmers in the higher age classes compared to the lower. If they retire, the farm will be sold to a younger farmer or transferred to the next generation (European Commission 2013). It is therefore worthwhile to focus on the younger generation of farmers with regard to future development of DST and likewise the evaluation of their WTP. This is supported by a recent survey of the European Council of Young Farmers among young farmers in Europe with regard to sustainability through agricultural practices. The results indicate that "young farmers are the new environmentalists because they acknowledge their responsibility in contributing to sustainability" (CEJA 2017 p.2). Furthermore, the younger farmers assess "knowledge development" as one of the most important factors in order to develop the farm in an economically sustainable way. This indicates that our sample of young and well-educated farmers is an appropriate basis for the investigation of the WTP for crop protection apps.

Moreover, the pesticide consumption of German agriculture has to be compared to other European countries in order to further judge the relevance of the results. In this context, the latest data of the agri-environmental indicator on consumption of pesticides shows that 400,000 tons of pesticides were sold in the European Union in 2014. The great producer countries Spain, France, Italy, and Germany made up 66.8% of the European Union's pesticide sales. Comparing the quantities of sold pesticides to each country's utilized agricultural area, the amounts of pesticides sold per hectare are nearly equal in these countries (Eurostat 2016). These numbers indicate that the consumption of crop protection products in Germany is not an extreme example in the European context. Hence, it is conceivable that the WTP for crop protection apps of farmers in other European countries with similar production conditions is influenced by similar factors. Nonetheless, further research in other European countries is necessary in order to examine the external validity of the results and to shed light on potential preference heterogeneity.

4 Conclusion

The digitalization of agriculture is one of the means to increase sustainability of agricultural production. Smartphone-based DST related to crop protection are a relatively new technological development that can be integrated into the production process to optimize crop protection strategies and potentially reduce negative externalities. This is the first study to explore factors influencing the willingness to pay for crop protection apps and assess which types of apps are perceived as useful by technologically experienced German farmers. This first insight allows us to draw some conclusions about factors that could facilitate or hinder adoption and contributes to the limited empirical evidence on utilization of smartphones by farmers.

Weather forecasts, tools to identify pests and diseases, as well as tools that are able to predict pests and diseases are perceived as useful by the majority of smartphone-experienced German farmers. Only 2 out of 174 respondents indicated that crop protection apps would not be useful at all. This finding highlights that apps can contribute to optimizing crop protection on the farm level as a convenient and mobile solution. Furthermore, the topics identified as useful can serve as a guideline for the future development of smartphone-based DST.

The vast majority of the surveyed German farmers are generally willing to pay for crop protection apps and several factors that influence this WTP have been identified. This mostly positive WTP emphasizes that farmers appreciate the utility of apps for their work processes and likewise has implications for app developers who hope to enhance existing smartphone-based DST. According to the results, we find that the perceived potential of cost reduction, the perceived potential to reduce negative environmental effects, the farmer's age, an agricultural university degree, knowledge of crop protection apps, as well as the farm size have a statistically significant effect on the WTP. The positive influence of perceived potential to reduce negative external effects on the WTP underlines that farmers are willing to increase the sustainability of their production. Furthermore, this supports the assumption that the WTP for environmental measures is not solely dependent on economic objectives, as environment protection and profit maximization can be partially conflicting.

Since all farmers in our sample were smartphone users, it is worth noting that still more than 22% did not have knowledge of any specific crop protection app. Therefore, there is great potential to increase the utilization of smartphones and apps as a DST for crop protection. The lack of knowledge of the respondents also provides clues regarding the future direction of marketing activities by developers. As smartphones and apps are relatively inexpensive compared to precision farming systems, they can serve as an economically feasible tool to improve the production process. This could prove relevant not only for large-scale agricultural producers but also for small producers, as well as in the context of extension services in developing countries (e.g., Janssen et al. 2017).

Some limitations of this study have to be considered in terms of the external validity of the derived results. The study is based on an online questionnaire which has led to a selection bias towards a group of German farmers with more information technology experience. The sample is not representative of German farmers. However, since the majority of respondents are current farm managers or successors, the conclusions which have been drawn are assumed to represent the general trends. To increase the validity of the results, an extension of the present study with a representative sample of German farmers could be of interest. Evaluating the extent of the farmers' WTP could also be of interest, as it would provide an extended understanding about the value farmers attribute to apps. The geographical location or profit-related factors might also be relevant for future research in the field of app usage.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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