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# Understanding the adoption of crop protection smartphone apps – An application of the Unified Theory of Acceptance and Use of Technology

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## Abstract

There is a steady increase in smartphone apps available to improve farmers' decision making with respect to crop protection. While current studies have focused on smartphone adoption in general and farmers' general willingness to pay for crop protection smartphone apps, none have focused on the initial adoption decision. Furthermore, it has not been studied yet which app functions are perceived as useful and which are actually used by farmers. Based on an online survey of 207 German farmers conducted in 2019, we investigated farmers' adoption decision for crop protection smartphone apps based on the Unified Theory of Acceptance and Use of Technology (UTAUT) framework applying partial least squares equation modelling and a binary logit model. Descriptive results show that 95 % of the surveyed farmers use a smartphone, but only 71 % use a crop protection smartphone app. Apps providing information about weather, pest scouting and infestations forecasts are perceived as most useful by the majority of farmers. However, reported use fell short of reported usefulness. All hypotheses of the UTAUT model could be verified. 72 % of the variation in the behavioral intention to use a crop protection smartphone app and 50 % of the variation in the actual adoption is explained by the model. The results are of interest for policy makers in the field of digitalization in agriculture as well as providers and developers of crop protection smartphone apps.

*Keywords:* crop protection, partial least squares structural equation modelling, precision agriculture, smartphone, smartphone apps, unified theory of acceptance and use of technology

## 1 Introduction

Crop protection becomes increasingly challenging for farmers due to increased management requirements related to the implementation of integrated pest management strategies. Selecting the best pest management strategies depends on a number of factors, inter alia, the early diagnosis and prediction of pest development. To facilitate a more sustainable agricultural intensification, recent research results and agronomic knowledge in form of practical recommendations need to be transferred to the farmers (Struik and Kuyper, 2017). One way to transfer this knowledge is the use of information and communication technology (ICT) based decision support tools (DST). Focusing on crop protection, these DST can play a major role in identifying diseases (Hallau et al., 2018), simulating disease development (Damos, 2015) and optimizing pesticide applications (Nansen et al., 2015). They have been shown, for instance, to reduce, herbicide applications while maintaining the same yield levels as the standard recommended applications (Sønderskov et al., 2015). These DST consequently have the potential to increase sustainability of agricultural productivity by reducing negative external effects and costs for agro-chemicals.

One recent category of DST are smartphone-based apps. Agricultural smartphone apps can be seen as a sub-area of precision agriculture technologies (PAT) for crop protection and can be integrated easily in farmers' daily work routine due to smartphones' high mobility. In contrast to other PAT, smartphones and respective apps do not require large investments, have large computational powers and can also utilize their in-build sensors (Michels et al., 2019b; Pongnumkul et al., 2015) allowing for farm and site specific data processing and use for agricultural production. However, a gap between the expectations of developers and the end users about the knowledge that should be included in DST, financial barriers or poor on-farm performance of the DST has been part of the reasons implementation of DST has been low (Lindblom et al., 2017; Matthews et al., 2008; Rose et al., 2016). Likewise, the adoption of smartphone apps for agricultural production fell short expectations (Hoffmann et al., 2014; Hoffmann et al., 2013).

To the best of our knowledge, no study has investigated determinants of the initial adoption decision. Bonke et al. (2018) have focused on socio-demographic and farm characteristics influencing the willingness-to-pay for crop protection apps. Considering the fact that many apps in the conventional download stores are free of charge, this article aims to study psychological factors influencing the adoption instead of sociodemographic and farm characteristics like age and farm size which are normally associated with farmers' investment and adoption decisions, for instance, for the adoption of PAT (e. g. Tey and Brindal, 2012). To gain a better understanding of farmers adoption decision we applied the Unified Theory of Acceptance and Use of Technology (UTAUT) introduced by Venkatesh et al. (2003). The UTAUT considers the psychological factors performance expectancy (PE), effort expectancy (EE), social influence (SI) and facilitating conditions (FC). Understanding psychological factors influencing farmers' adoption decision can help to explain and predict crop protection app adoption by farmers and guide future development.

Furthermore, it has been repeatedly recognized that the development of DST are conditional on the involvement of farmers as the targeted end-users in the development process (e.g. Inwood and Dale, 2019; Rose et al., 2016). Up to now, no study has focused on the functions of a crop protection app farmers find useful and which are used simultaneously. While Bonke et al. (2018) assessed which crop protection apps are perceived as useful, they did not assess which types are already used. In contrast, Wright et al. (2018) reported the use of apps, but not which apps farmers perceive as useful. However, evaluating usefulness and use simultaneously provides important insights which can direct future development of smartphone based DST in crop protection since it directly shows the contrast between expectations and actual use.

The novelty of this article is therefore twofold: This is the first study explicitly focusing on the crop protection smartphone app adoption. We therefore examine if the UTAUT framework can contribute to the understanding of underlying psychological factors influencing the adoption of crop protection smartphone apps by farmers. Furthermore, this is the first study considering simultaneously which apps are perceived as useful and which apps are also used by farmers. Based on an online survey with 207 farmers conducted in 2019, we estimated the UTAUT using partial least squares (PLS) structural equation modelling and a binary logit model. The results are of interest of policy makers with respect to digitalization in agriculture as well as developers and providers of crop protection smartphone apps.

The remainder of the article is organized as follows: In the next chapter the theoretical framework of the UTAUT model is presented. Chapter 3 contains the applied material and methods. The results are presented and discussed in chapter 4. The article closes with its final remarks in chapter 5.

## 2 Theoretical Framework

This study is based on a modified UTAUT model for the adoption of crop protection smartphone apps. The UTAUT model was developed by Venkatesh et al. (2003) as an integrative approach and combines variables from eight distinct theories. While the TAM (Davis, 1989) is the most widely applied model for the adoption of ICT (Verma and Sinha, 2018), the UTAUT model has the best predictive power (e.g. San Martín and Herrero, 2012). Our modified UTAUT model for the adoption of crop protection smartphone apps will be explained in the following and is graphically displayed in Figure 1.

In the UTAUT model PE refers to the extent to which an individual believes that the use of a technology facilitates performing a task or improves his or her job performance and has a positive effect on an individuals' behavioral intention to use (BI) a technology (Venkatesh et al., 2003). For crop protection smartphone apps, Bonke et al. (2018) show that farmers' beliefs that crop protection smartphone apps can reduce external environmental effects and costs have a positive effect on their general willingness to pay. In a complementary manner, time savings through simplified documentation can be expected. Hence, the following hypothesis is derived:

> **H1**: Performance expectancy of crop protection smartphone apps has a positive effect on the behavioral intention to use crop protection smartphone apps

EE is defined as the degree of ease an individual associates with using a system and a positive effect on BI is assumed (Venkatesh et al., 2003). Rose et al. (2016) emphasize, based on qualitative interviews with farmers, that smartphone apps for agricultural purposes should be simple and user-friendly. Likewise, Michels et al. (2019a) show that dairy farmers' perceived ease of use has a positive effect on the frequency of dairy herd management smartphone app use, ultimately. Furthermore, information provided should be easy to understand and provided instantaneous (Rose et al., 2016). This in accordance with the TAM (Davis, 1989) which suggests that perceived ease of use has a positive effect on perceived usefulness of a technology since the easier a technology is to use, the higher the perceived usefulness, *ceteris paribus*. Hence, the following hypotheses are derived:

> **H2a**: Effort expectancy of crop protection smartphone app use has a positive effect on the behavioral intention to use crop protection smartphone apps
>
> **H2b**: Effort expectancy of crop protection smartphone app use has a positive effect on performance expectancy of crop protection smartphone apps

Venkatesh et al. (2003) define SI as the extent to which an individual believes that important people in their surrounding think that he or she should use a new technology. Kuczera (2006) shows that farm decisions are influenced by other farmers. In an extension of the TAM, Venkatesh and Davis (2000) hypothesize that SI has a positive effect on perceived usefulness. Thus, if farmers' colleagues believe that crop protection smartphone apps are very beneficial, for instance, to facilitate documentation, a farmer may come to the belief that a crop protection smartphone app actually is useful for that purpose. The following hypotheses will therefore be tested:

> **H3a**: Social influence has a positive effect on the behavioral intention to use crop protection smartphone apps
>
> **H3b**: Social influence has a positive effect on performance expectancy of crop protection smartphone apps

FC are characterized by Venkatesh et al. (2003) as the degree to which an individual perceives that the present technical infrastructure supports the use of the technology in question and has a direct influence on the adoption decision. Michels et al. (2019b) suggest that insufficient mobile internet coverage could limit smartphone adoption. Likewise, some crop protection smartphone apps may need mobile internet access to retrieve data for the identification of weeds or weather updates. More importantly, the smartphone itself has to be suitable for the installation of crop protection smartphone apps. In the original UTAUT model Venkatesh et al. (2003) excluded the influence of FC on BI since this relationship is, according to the authors, already taken into account by the relationship between PE, EE and BI, respectively. Nevertheless, some studies have demonstrated an effect of FC, besides PE and EE, on BI (e.g. Dwivedi et al., 2017). We therefore propose the following hypotheses:

**H4a**: Facilitating conditions have a positive effect on the adoption decision for crop protection smartphone apps

**H4b**: Facilitating conditions have a positive effect on the behavioral intention to use crop protection smartphone apps

Venkatesh et al. (2003) found empirical support in their UTAUT model that the BI ultimately has a positive effect on the actual adoption behavior. Hence, the following hypothesis is derived:

**H5**: Behavioral intention to use a crop protection smartphone app has a positive effect on the actual crop protection smartphone app adoption

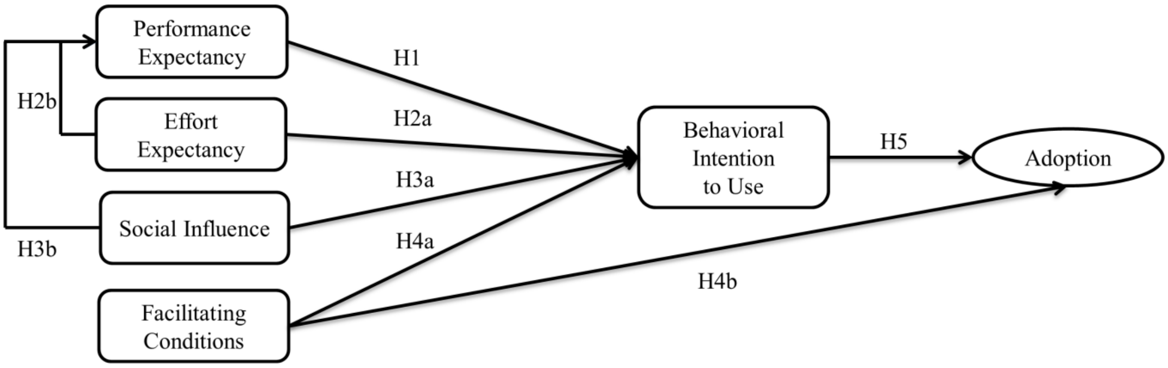

**Fig. 1.** Proposed modified UTAUT model for the adoption of crop protection smartphone apps

## 3 Material and Methods

### *3.1 Data collection*

An online survey[1] addressed to farmers was conducted in Germany in the first quarter of 2019. Contact was made through various groups on social media platforms, agricultural online forums and newsletters. 207 fully completed questionnaires remained as usable records after the removal of incomplete surveys. The survey can be divided into three parts: In

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[1] Precondition for the survey was to be active in arable farming.

the first part, the participants were asked to enter information on socio-demographic and farm related characteristics. In the second part of the survey the farmers were asked about the operational use of ICT and specific crop protection apps. In the third part, the farmers were requested to give their approval to 14 randomized statements, which were taken to represent the constructs of the proposed UTAUT. The statements were derived from Venkatesh et al. (2003) but adapted to the topic of crop protection smartphone apps.

### *3.2 Partial least squares structural equation modelling*

In order to estimate the previously described UTAUT model (see Figure 1), we used structural equation modelling, since we wanted to simultaneously estimate the relationship between constructs as well as the relationship between indicators and constructs. Specifically, we applied PLS structural equation modelling, as this approach is less restrictive concerning the structure of the data than covariance-based structural equation modelling which requires normally distributed data. Furthermore, PLS structural equation modelling allows the use of constructs with only one or two items (Hair et al., 2011). PLS structural equation modelling aims to maximize the explained variance of the endogenous variables. The model consists of two parts: the outer (relationship between indicator and construct) and the inner model (causal relationship between constructs) (Hair et al., 2016).

Following Hair et al. (2016), the evaluation of PLS structural equation modelling results follows two steps. In the first step, the outer model is assessed followed by the inner model in the second step. For the assessment of the outer model of the estimated UTAUT model indicator reliability, internal consistency reliability, convergent validity, and discriminant validity are tested. Indicator reliability refers to the extent to which a construct explains each indicator's variance. The associated cut-off level for the standardized loadings is > 0.7. Internal consistency reliability refers to the extent to which the indicators measure the same construct.

In our case, internal consistency reliability is approved by the estimation of composite reliability (CR). The associated cut-off level is > 0.7. Convergent validity can be assumed if the average variance extracted (AVE) is above the threshold of 0.5. AVE describes to which extent the model captures variance from its indicators compared to the amount of variance captured due to measurement errors. Discriminant validity refers to the extent to which the constructs are separable from other constructs. In our study, discriminant validity is established by the Heterotrait-Montotrait (HTMT) criterion. The HTMT ratios should be below 0.9 (Hair et al., 2016). Since OLS regression serves as basis for the calculation of the path coefficients, the bias of those path coefficients by possible multicollinearity between the constructs must be explored. To account for multicollinearity, variance inflation factors (VIF) are estimated. Values of the VIFs should be below five (Hair et al., 2016; Hair et al., 2011).

For the evaluation of the inner model, explained variance ($R^2$) and the out-of-sample predictive relevance (Stone-Geisser criterion $Q^2$) (Geisser, 1974; Stone, 1974) are estimated. $Q^2$ is estimated by using blindfolding with an omission distance of seven. Since no assumption about the distribution of the data is needed for PLS structural equation modelling, results for hypotheses testing of the path coefficients of the inner model are derived from a re-sample bootstrapping procedure. According to Hair et al. (2014) at least 5,000 subsamples should be applied to generate t-values to allow for hypothesis testing. Estimation of the proposed UTAUT model was carried out using SmartPLS 3.2.7 (Ringle et al., 2015).

### *3.3 Logistic regression*

To avoid biased standard errors by using a dummy variable as an endogenous variable in PLS structural equation modelling (Hair et al., 2012), we applied a binary model. For dichotomous variables (1 = adoption of crop protection smartphone app; 0 = non adoption) probit or logit models can be used. Assuming a standard logistic distribution of the error term (Verbeek, 2008), we applied a binomial logit model. In specific, the effect of BI and FC on the actual adoption decision (Figure 1) was modelled by implementing the latent factor scores for BI and FC as the independent variables and the dummy variable for the actual adoption decision as the dependent variable in a binary logit model. We also performed specification tests for the model displayed the next section.

## 4 Results and discussion

### *4.1 Descriptive results*

Table 1 provides an overview of the descriptive statistics for the sociodemographic and farm characteristics. The sample includes younger, formally better educated full-time farmers with more arable land than the average German farmer. Nevertheless, evidence from the literature listed confirms that younger and formally better educated farmers managing larger farms are more likely to adopt PAT (e.g. Paustian and Theuvsen, 2017; Pierpaoli et al. 2013; Barnes et al., 2019). It can be expected that the younger, well-educated farmers will most likely be long-time users of these digital technologies (Bonke et al., 2018; Rose et al., 2016). Therefore, focussing on their motives and obstacles for the adoption is crucial to maintain use by these farmers. Likewise, investigating early adopters' motives and obstacles can help to facilitate widespread adoption. The smartphone leads the list of IT devices used for farm business purposes (Table 2). Ninety-five percent of the farmers in the sample use a smartphone followed by the PC which is used by 79 % of the farmers. On average, the surveyed farmers owned a smartphone for 7 years with 5 apps used for agricultural purposes. Eighty-two percent of the farmers in the sample were aware of crop protection smartphone apps and 72 % already use them. With respect to crop protection apps, on average two apps were used by the farmers who stated they were using crop protection smartphone apps on their farm. Most farmers use apps which are for free, since on average only 0.34 apps were subject to a fee.

**Table 1**
Descriptive Statistics for sociodemographic and farm characteristics (n = 207)

| **Variable** | **Description** | **Mean** | **Std. Dev.** | **Min** | **Max** | **German Average1)** |
|---|---|---|---|---|---|---|
| Age | Farmers' age in years | 39.13 | 11.90 | 19 | 67 | 53 |
| Arable land | Hectares of arable land | 297.90 | 486.67 | 4 | 3800 | 60 |
| Conventional | 1, if the farm is managed conventional; 0 otherwise | 0.85 | - | 0 | 1 | 0.89 |
| Education | 1, if the farmer has a university degree; 0 otherwise | 0.52 | - | 0 | 1 | 0.12 |
| Full-time | 1, if the farmer is employed as a full-time farmer; 0 otherwise | 0.90 | - | 0 | 1 | 0.48 |
| Gender | 1, if the farmer is male; 0 otherwise | 0.94 | - | 0 | 1 | 0.90 |
| Lease proportion | % of leased arable land of total land managed | 0.54 | 0.24 | 0 | 0.99 | 0.59 |
| Region | | | | | | |
| East | 1, if the farm is located in Brandenburg, Saxony, Saxony-Anhalt or Thuringia | 0.12 | - | 0 | 1 | 0.07 |
| North | 1, if the farm is located in Schleswig-Holstein, Lower Saxony or Mecklenburg Western Pomerania | 0.36 | - | 0 | 1 | 0.20 |
| South | 1, if the farm is located in Baden-Württemberg or Bavaria | 0.31 | - | 0 | 1 | 0.47 |
| West | 1, if the farm is located in North Rhine-Westphalia, Hesse, Rhineland Palatinate or Saarland | 0.20 | - | 0 | 1 | 0.24 |

1) German Farmers' Federation (2019)

**Table 2**
Usage of ICT and crop protection smartphone apps

| **Variable** | **Description** | **Mean** | **Std. Dev** | **Min** | **Max** |
|---|---|---|---|---|---|
| Smartphone | 1, if the farmer has a smartphone; 0 otherwise | 0.95 | - | 0 | 1 |
| Mobile phone | 1, if the farmer has a mobile phone; 0 otherwise | 0.16 | - | 0 | 1 |
| PC | 1, if the farmer has a PC; 0 otherwise | 0.79 | - | 0 | 1 |
| Laptop | 1, if the farmer has a laptop; 0 otherwise | 0.66 | - | 0 | 1 |
| Tablet | 1, if the farmer has a tablet; 0 otherwise | 0.48 | - | 0 | 1 |
| SmartphoneExp1) | Average smartphone ownership in years | 7.62 | 2.47 | 1 | 11 |
| NumberAgriApp1) | Average number of smartphone apps used for agricultural purposes | 5.10 | 3.65 | 0 | 15 |
| AwareCropApp1) | Share of farmers in % that were aware of any smartphone app related to crop protection | 0.82 | - | 0 | 1 |
| UsageCropApp1) | Share of farmers in % that were actually using a crop protection smartphone app | 0.71 | - | 0 | 1 |
| NumberCropApp2) | Number of crop protection smartphone apps being used | 2.21 | 1.30 | 1 | 8 |
| NumberCropAppPurch2) | Number of purchased crop protection smartphone apps | 0.34 | 0.60 | 0 | 3 |

1) Mean and standard deviation shown for the share of farmers who have a smartphone (Variable Smartphone = 1; n = 198)

2) Mean and standard deviation shown for the share of farmers who use a crop protection smartphone app (Variable UsageCropApp = 1; n = 143)

With regard to the function of crop protection smartphone apps (Table 3), forecasting, monitoring and documentation features in particular, but also calculations aids and supporting information on product or nozzle choices were perceived as useful. One exception is the result for the apps providing weather information. Seventy-seven percent of the farmers reported them as useful, while 83 % stated they are using them. This result could be explained by the fact that weather apps are installed by default on most smartphones, which also explains the fact that 72 % of the farmers reported the actual use of crop protection smartphone apps (Table 2) but 83 % use a weather app (Table 3). Furthermore, some farmer might have not considered the weather app explicitly as a crop protection smartphone app.

**Table 3**
Responses regarding the perceived usefulness and actual use of apps related to various crop protection topics (n = 198)$^{1)}$

| **Function of Crop Protection Smartphone Apps** | **Percent Reporting Considered as useful** | **Percent Reporting Already in Use** |
|---|---|---|
| Weather information | 0.77 | 0.83 |
| Pest scouting | 0.75 | 0.52 |
| Infestation forecast | 0.64 | 0.24 |
| Field file/ documentation | 0.62 | 0.39 |
| BBCH determination | 0.51 | 0.34 |
| Product choice | 0.51 | 0.11 |
| Calculation of application quantity of fertilizer | 0.44 | 0.15 |
| Calculation of application quantity of spraying product | 0.40 | 0.10 |
| Recommendations on spray nozzles | 0.39 | 0.08 |
| Planning of crop rotation | 0.38 | 0.07 |
| Manufacturer recommendation | 0.27 | 0.05 |
| Other function | 0.08 | 0.06 |

$^{1)}$ Mean shown for the share of farmers who have a smartphone (Variable Smartphone = 1)

### *4.2 Evaluation of the outer measurement model*

The reflective measures were evaluated with respect to indicator reliability, composite reliability, convergent validity and discriminant validity. The results of the evaluation can be found in Table 4 and Table 5. Indicator loadings are - with one exception - above the common cut-off level of 0.7 with the lowest loading for the indicator PE4 with 0.709. Furthermore, all indicator loadings are statistically significant. Further proof of the validity of the outer reflective indicators can be found in the values of composite reliability and AVE, which all exceed the cut-off levels of 0.7 and 0.5, respectively. Lastly, all values for the HTMT ratios are below the cut-off level of 0.9 also proving the discriminant validity of the outer model

(Hair et al. 2016). Therefore, the validity of the outer model is proofed. To check for possible multicollinearity issues, inner VIFs are estimated (min. VIF = 1.295; max VIF = 2.977). Since all inner VIFs' values of the relationships between the constructs are below the critical value of 5, the path coefficients can be estimated and discussed as follows in the next section (Hair et al., 2016).

**Table 4**
Descriptive statistics for the indicators as well as evaluation results for the related reflective constructs (n = 207)

| **Construct** Indicator | **Statement** | **Mean** | **Std. Dev** | **Loadings** | **CR** | **AVE** |
|---|---|---|---|---|---|---|
| **Performance Expectancy (PE)** | | | | | 0.902 | 0.699 |
| PE1 | I would find the use of crop protection smartphone apps useful in my day-to-day work | 2.93 | 1.20 | 0.860*** | | |
| PE2 | I think using crop protection smartphone apps would make my crop protection more cost-effective | 3.39 | 1.26 | 0.881*** | | |
| PE3 | I think crop protection smartphone apps would make crop protection more environmentally friendly | 3.12 | 1.28 | 0.883*** | | |
| PE4 | I think that crop protection smartphone apps would speed up my work completion | 3.11 | 1.21 | 0.709*** | | |
| **Effort Expectancy (EE)** | | | | | 0.897 | 0.744 |
| EE1 | The handling of a crop protection smartphone app would be simple and understandable for me | 3.58 | 1.15 | 0.850*** | | |
| EE2 | All in all, I would find crop protection smartphone apps to be easy to use tools | 4.07 | 1.03 | 0.832*** | | |
| EE3 | I believe that the use of crop protection smartphone apps would be easy for me to learn | 3.49 | 1.15 | 0.903*** | | |
| **Social Influence (SI)** | | | | | 0.857 | 0.749 |
| SI1 | Farmers who are friends of mine think that it makes sense to use a crop protection smartphone app | 3.14 | 1.03 | 0.847*** | | |
| SI2 | My work colleagues think that I should use crop protection smartphone apps | 2.45 | 1.15 | 0.884*** | | |
| **Behavioral Intention to use (BI)** | | | | | 0.971 | 0.918 |
| BI1 | I plan to use crop protection smartphone apps | 3.37 | 1.32 | 0.960*** | | |
| BI2 | I intend to use crop protection smartphone apps | 3.47 | 1.31 | 0.953*** | | |
| BI3 | It is likely that I will use crop protection smartphone apps in the future | 3.22 | 1.33 | 0.961*** | | |
| | **Single item construct** | | | | | |
| **Facilitating Conditions (FC)** | | | | | | |
| FC | My smartphone and mobile internet coverage are sufficient to use a crop protection smartphone app | 3.50 | 1.37 | - | - | - |

A second item for FC was removed due to loadings and CR below 0.7
Loadings > 0.7; CR > 0.7; AVE > 0.5
*p-value < 0.05, **p-value < 0.01, ***p-value < 0.001

**Table 4**
Discriminant validity – Heterotrait-Monotrait ratios (n=207)

| | FC | EE | BI | PE | SI |
|---|---|---|---|---|---|
| FC | | | | | |
| EE | 0.521 | | | | |
| BI | 0.335 | 0.821 | | | |
| PE | 0.340 | 0.883 | 0.889 | | |
| SI | 0.267 | 0.698 | 0.788 | 0.781 | |

PE = Performance expectancy, EE = Effort expectancy, SI = Social influence, BI = Behavior-al intention to use, FC = Facilitating conditions
HTMT < 0.9

### *4.3 Estimation results of the UTAUT model*

Before drawing conclusions for the hypotheses outlined in section 2, $R^2$, $Q^2$, Pseudo-$R^2$ and several specification tests for the PLS structural equation model and the binary logit model are taken into account, respectively. $R^2$ and $Q^2$ amount to 0.732 and 0.654 for the IU and 0.623 and 0.421 for PE in the PLS structural equation model (Table 6), respectively. Values for $R^2$ above 0.67 and 0.33 can described as substantial and moderate, respectively (Chin, 1998). Furthermore, a value above 0.7 for the IU corresponds to the results of Venkatesh et al. (2003). Basically, $Q^2$ scores greater than zero imply sufficient out-of-sample predictive relevance. Another conclusion can be drawn by comparing $R^2$ and $Q^2$, because the closer the two values are to each other, the smaller the prediction error and the greater the prediction accuracy of the model (Hair et al., 2016). The predictive power is comparable to other UTAUT studies in the agricultural context, for instance the adoption of irrigation technology (Nejadrezaei et al., 2018).

A statistically significant likelihood-ratio test indicates that the null hypothesis of all coefficients in the binary logit model being equal to zero can be rejected. Furthermore, the Pearson as well as the Hosmer-Lemeshow test were not statistically significant, indicating no misspecification of the model. The model predicted 84.54 % of the observations correctly. The specification and classification results are comparable or better than results for computer and internet adoption in agriculture (Batte, 2005; Briggeman and Whitacre, 2010) or the adoption of PAT (e.g. Paustian and Theuvsen, 2017). The Nagelkerke Pseudo-$R^2$ value of 0.50 for the adoption indicates a comparatively good fit of the binary logit model. The results are also given in the lower part of Table 6.

**Table 6**
Estimation results of the UTAUT model (n=207)[1]

| *PLS structural equation model*[2] | | | | |
|---|---|---|---|---|
| **$H_0$** | | **Path coefficients** | **t-statistic**[3] | **Supported $H_0$** |
| PE→BI | H1 | 0.521*** | 7.532 | Supported |
| EE→BI | H2a | 0.244*** | 3.959 | Supported |
| EE→PE | H2b | 0.633*** | 14.512 | Supported |
| SI→BI | H3a | 0.184** | 3.158 | Supported |
| SI→PE | H3b | 0.268*** | 5.195 | Supported |
| FC→BI | H4a | 0.008 | 0.210 | Not supported |
| *Binary logit model*[4] | | | | |
| **$H_0$** | | **Odds ratio** | **Std. Error** | **Supported $H_0$** |
| FC→Adoption | H4b | 1.613* | 0.322 | Supported |
| BI→Adoption | H5 | 5.065*** | 1.196 | Supported |

[1] PE = Performance expectancy, EE = Effort expectancy, SI = Social influence, BI = Behavioral intention to use, FC = Facilitating conditions
[2] PE ($R^2$ = 0.654, $Q^2$ = 0.421), BI ($R^2$ = 0.732, $Q^2$ = 0.623)
[3] Bootstrap results 5,000 subsamples
[4] Log likelihood = -82.501; LR chi$^2$(2) = 91.03***; Nagelkerke Pseudo $R^2$ = 0.50; Pearson chi2(72) = 75.58, p-value = 0.36; Hosmer-Lemeshow chi2(8) = 10.74 p-value = 0.21; Correctly classified = 84.54 %
*p-value < 0.05, **p-value < 0.01, ***p-value < 0.001

The upper part of Table 6 shows the results of the PLS structural equation model. The path coefficient PE→BI is statistically significant and has the expected positive sign. Furthermore, the numeric value of the path coefficient of PE→BI is the second highest in the model, indicating a relatively high importance of PE expressed by the farmers. As noted in the development of the UTAUT by Venkatesh et al. (2003), PE shows the strongest effect on BI by having the highest numeric path coefficient, which is not entirely true in our case. Nevertheless, **H1** is supported by our model. This finding is consistent with a large body of literature on the adoption of PAT in agriculture (e.g. Barnes et al., 2019; Fountas et al., 2015). Pierpaoli et al. (2013) concluded in their literature review on the adoption of PAT that improving productivity is the primary motivation for farmers to implement PAT. Furthermore, Bonke et al. (2018)

show that German farmers a more likely to have a general willingness-to-pay for crop protection smartphone apps if they perceive them as useful for reducing externalities in crop protection and production costs. Our results are also in line with the findings of Evans et al. (2017) and Rose et al. (2018). Both studies come to conclusion that if the (financial) benefits of DST can be mediated, adoption of DST could be increased. It is very likely that farmers will not download and install a crop protection smartphone app if the app shows no value for them, even though most of the available crop protection smartphone apps are free. Likewise, farmers will stop using an app if it has no value for them and delete the app since it takes up storage space, which can be used for more suitable smartphone apps (Yuan et al., 2015). To increase the perceived performance of a smartphone app with respect to crop protection, developers and providers should consider providing, for instance, user-oriented information based on the crop specialization of the farm. Similarly, weather apps or apps with respect to pest scouting or infestation forecasting should explicitly consider the farmers' location. In this context, an early warning system established as a push notification could increase farmers' perceived performance of the crop protection smartphone app. In line with that, Rose et al. (2016) proposed that DST should provide information which are relevant to the farmer. With possibilities to personalize the app the relevance and ultimately the performance of the app could be increased. This result also implies that developers and providers of apps should focus communicating the benefits of their app offered in the respective download stores to increase the likelihood of initial uptake by farmers.

**H2a** and **H2b** test the effect of EE on BI and of EE on PE. The path coefficients are statistically significant and have the expected positive signs. Hence, our model supports **H2a** and **H2b**. The support for **H2a** implies that if farmers perceive the usage of crop protection apps in their working routine as relatively effortless, they have a higher intention to use them. This result is in line with Venkatesh et al. (2003). Likewise, literature on the PAT adoption suggests that computer literacy increases farmers' chances to adopt a PAT. With a higher computer literacy, a farmer perceives the use of a PAT as easier (Pierpaoli et al., 2013). Moreover, Michels et al. (2019a) showed that dairy farmers who perceive using a herd management smartphone app as easy are more likely to use such an app more frequently. From this result, some important implications can be drawn for developers and providers of apps. Basically, it can be concluded that farmers won't use an app if it is too difficult in use. In the field of health apps, Wang et al. (2014) found that if the amount of time and effort needed to effectively use a smartphone app increases, users' motivation to use such an app decreases. Thus, handling of crop protection smartphone apps should be kept as easy as possible. In line with the implications for **H1**, easy handling of a crop protection smartphone app should directly be communicated in the download store along with the potential benefit of using the app itself. Given the nature of smartphone or tablet apps, they undergo frequent updates and modifications. While this is positive, as it might increase perceived performance for the farmers, providers should consider not changing the interface and design of an app too often or to drastically. Beldad and Hegner (2018) also concluded that the interface of an app matters. They suggested that people want to use an app by simply "clicking". Thus, to fully explore the benefit of an app, the app has to be easy to handle and well structured (Beldad and Hegner, 2018) to access all information desired. This can also be concluded from the support for **H2b** provided by our model. The path coefficient EE→PE shows the highest numerical value in our model. Considering the daily working routine of a farmer, information provided by the app should be reachable in an easy, fast and user friendly manner. According to our results, developers of such apps should focus on that.

**H3a** and **H3b** deal with the effect of SI on BI and PE, respectively. The path coefficients are statistically significant and have the expected positive signs. Thus, both hypotheses are supported by our model. The support for **H3a** implies that farmers' colleagues have an influence on the individual farmer's adoption decision. The result is in line with Venkatesh et al. (2003). Previous studies on the adoption of PAT also attribute a major role to the exchange of information and experiences among farmers (e. g. Marra et al., 2010; Pignatti et al., 2015; Reichardt and Jürgens, 2009). Likewise, Brudermann et al. (2013) were able to confirm networks between farmers for the adoption of photovoltaic plants in Germany. The statistically significant path coefficient of SI→PE, which was tested in **H3b**, can be explained with Deutsch and Gerard (1955). According to the authors, our observed effect can be described as the "[…] influence to accept information from another as evidence about reality" (Deutsch und Gerard, 1955, p. 629). Considering the fact that not all farmers who have a smartphone also use a crop protection smartphone app or are aware of it, this result offers some important implications for the marketing of such apps. Paustian and Theuvsen (2017) as well as Michels et al. (2019b) identified younger, well-educated and innovative farmers from larger farms as being more likely to be adopters of PAT and smartphones, respectively. They concluded that marketing activities should focus on these target groups. Taken into account that SI has a direct effect on BI as well as an indirect effect over the path with PE, marketing activities should also focus on these target groups since it's most likely that these farmers are also adopters of crop protection smartphone apps. These farmers can influence current non-adopters directly or indirectly by convincing them of the benefits of using a crop protection smartphone app.

**H4a** and **H4b** deal with the effect of FC on BI and the actual adoption of crop protection smartphone apps, respectively. Our model does not support **H4a**, since the path coefficient is not statistically significant despite having the expected positive sign. However, this result is in accordance with Venkatesh et al. (2003) that the influence of FC on BI has already been covered by the effect of EE on BI. Furthermore, it can be assumed that the facilitating conditions are only considered in the actual adoption which is captured by **H4b**. Our binary logit model supports **H4b** which is displayed in the middle part of Table 6. The binary logit model captures the direct effect of exogenous variables on the actual adoption decision. The coefficients of the binary logit model are given as odds ratios. An odds ratio above 1 indicates a positive effect on the dependent variable; an odds ratio below 1 a negative effect. The expected positive effect of FC on the adoption is proven to be statistically significant with odds greater than 1, i.e., facilitating conditions increase the likelihood of crop protection smartphone app adoption. Literature on the adoption shows that a sufficient technological infrastructure on the farm encourages farmers to adopt PAT. Moreover, a smooth and easy integration of a new PAT in the existing technological structure on the farm increases the likelihood of adoption (Barnes et al., 2019; Fielding et al., 2008; Pignatti et al., 2015). More specific, our results confirm Rose et al. (2016, p. 171) that for instance, poor (mobile) internet access can result "[…] in a mismatch between tool and end user workflow […]". Regarding crop protection smartphone apps it can be assumed that they are mostly applied in the field, for instance, to identify a weed. Thus, missing connection could limit farmers' access to the data base to retrieve the information needed. As, for instance, German farmers still have a demand for faster internet in rural areas (German Farmers' Federation, 2017) and the internet becomes increasingly important for the adoption of PAT (Khanna and Kaur, 2019) developers should consider that crop protection smartphone apps should also be usable offline, at least to a certain extent. Moreover, policy makers are encouraged to consider putting a higher focus on developing mobile internet coverage in rural areas.

Lastly, **H5** deals with the effect of BI on the actual adoption of crop protection smartphone apps. The odds ratio estimated in a binary logit model is greater than 1; i.e. a higher BI increases the likelihood of a crop protection smartphone apps adoption. This is in accordance with Venkatesh et al. (2003). As expected, BI is a predictor of the actual adoption decision. In conclusion, all the hypotheses of the classical UTAUT can be confirmed for the adoption crop protection smartphone apps by German farmers.

## 5. Concluding remarks

Crop protection apps, as form of smartphone-based DST, can contribute to sustainable agricultural intensification as a direct provider of agronomic knowledge to farmers. Considering the fact that most crop protection smartphone apps are for free, this study focus on psychological factors influencing the adoption decision. Therefore, this is the first study implementing an extended UTAUT model to gain insights into behavioural aspects of farmers' adoption of crop protection apps. The study is based on an online survey of 207 German farmers in 2019. The UTAUT model is estimated using PLS structural equation modelling and a binary logit model. Seven of the eight hypotheses were supported by our model.

In line with the literature, the key constructs performance expectancy, effort expectancy, social influence and facilitating conditions influence the adoption decision. Furthermore, this study assesses which crop protection smartphone apps are perceived as useful and which functions are really used by the farmers. The descriptive results show that not all farmers who perceive a crop protection smartphone app function as useful actually use a corresponding app. The apps which are perceived as most useful should be therefore further developed and improved since these apps are the ones the farmers are most likely to use.

In order to increase the uptake, the results of the UTAUT provide several implications. The benefits of using such a crop protection smartphone app should be self-evident for farmers in the initial screening stage in the download store and, more importantly, while using the app. Options to personalize the information a farmer retrieves from the app based on farm specialisation and location could increase farmers' uptake. The interface of an app should be kept as simple as possible. Furthermore, developers and providers should consider that an app designed for on-field application should work offline.

Further research should investigate why farmers who perceive an app function as useful do not use the app itself. This could be useful for developers and providers in order to explore why expectations of a crop protection smartphone app fell so far apart from its actual abilities. Furthermore, it should be tested if our results hold true of other smartphone apps dedicated to different areas of the agricultural production.

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**Department für Agrarökonomie und Rurale Entwicklung**

Die Wurzeln der **Fakultät für Agrarwissenschaften** reichen in das 19. Jahrhundert zurück. Mit Ausgang des Wintersemesters 1951/52 wurde sie als siebente Fakultät an der Georgia-Augusta-Universität durch Ausgliederung bereits existierender landwirtschaftlicher Disziplinen aus der Mathematisch-Naturwissenschaftlichen Fakultät etabliert.

1969/70 wurde durch Zusammenschluss mehrerer bis dahin selbständiger Institute das **Institut für Agrarökonomie** gegründet. Im Jahr 2006 wurden das Institut für Agrarökonomie und das Institut für Rurale Entwicklung zum heutigen **Department für Agrarökonomie und Rurale Entwicklung** zusammengeführt.

Das Department für Agrarökonomie und Rurale Entwicklung besteht aus insgesamt neun Lehrstühlen zu den folgenden Themenschwerpunkten:

- Agrarpolitik
- Betriebswirtschaftslehre des Agribusiness
- Internationale Agrarökonomie
- Landwirtschaftliche Betriebslehre
- Landwirtschaftliche Marktlehre
- Marketing für Lebensmittel und Agrarprodukte
- Soziologie Ländlicher Räume
- Umwelt- und Ressourcenökonomik
- Welternährung und rurale Entwicklung

In der Lehre ist das Department für Agrarökonomie und Rurale Entwicklung führend für die Studienrichtung Wirtschafts- und Sozialwissenschaften des Landbaus sowie maßgeblich eingebunden in die Studienrichtungen Agribusiness und Ressourcenmanagement. Das Forschungsspektrum des Departments ist breit gefächert. Schwerpunkte liegen sowohl in der Grundlagenforschung als auch in angewandten Forschungsbereichen. Das Department bildet heute eine schlagkräftige Einheit mit international beachteten Forschungsleistungen.

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