Understanding German farmer's intention to adopt mixed cropping using the theory of planned behavior

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Abstract

The diversification of cropping systems has the potential to contribute towards a sustainable land use while preserving biodiversity. Mixed cropping is one possibility to increase biodiversity within farming systems. However, adoption of mixed cropping systems is challenging for farmers, as the agricultural sector has evolved around pure stands over the past decades and path dependencies have emerged. Yet, little is known about farmers' motivation to adopt mixed cropping. Utilizing the theory of planned behavior as the main framework, this paper studies the psychological factors underlying farmers' intention to adopt mixed cropping based on an online survey with 172 German farmers. In addition, the most crucial adoption obstacles are assessed. Using partial least squares structural equation modeling, we show for the first time that attitude, perceived behavioral control, and injunctive as well as descriptive group norms explain over 52% of farmers' intention to adopt mixed cropping. Our results also demonstrate that perceived ecological benefits positively influence a farmer's attitude towards mixed cropping. Missing sales opportunities for mixed yields, the uneven maturing of crops, and deficient economic benefits are ranked as the most crucial obstacles for the implementation of mixed cropping. These results, which can be relevant for other European countries as well, indicate that the introduction of a voluntary agri-environmental scheme could encourage adoption and that considering positive effects of group norms within policy schemes could further increase adoption on a large scale.

Keywords Mixed cropping adoption · Theory of planned behavior · Partial least squares structural equation modeling · Logit model

1 Introduction

The sustainable intensification of agriculture and conservation of biodiversity are major challenges that the agricultural sector is currently facing. The diversification of cropping systems has the potential to contribute to sustainable intensification while also preserving biodiversity (Meynard et al. 2018; Rosa-Schleich et al. 2019). One possibility to diversify cropping systems, which has not received much attention by European farmers in the recent past, is the application of mixed cropping systems (e.g., Martin-Guay et al. 2018). One form of mixed

cropping, also referred to as intercropping or the cultivation in mixed stands, is the simultaneous cultivation of two or more coexisting main crops in one field (e.g., Gaba et al. 2015). Especially the cultivation of non-legumes and legumes in mixed stands can provide a number of benefits due to the application of basic ecological concepts and the ability of legumes to fixate atmospheric nitrogen (e.g., Bedoussac et al. 2015; Rosa-Schleich et al. 2019) (Fig. 1). Reduced requirements for synthetic fertilizers, improved water use efficiency, and decreased nitrogen leaching are some examples of the advantages associated with mixed stands (e.g., Gaba et al. 2015).

Nevertheless, since the agricultural sector has evolved around pure stands over the past few decades and path dependencies have emerged, changing the production systems towards mixed stands is challenging for farmers (e.g., Bedoussac et al. 2015; Lemken et al. 2017). Learning and opportunity costs arise if farmers change towards mixed cropping, decreasing the potential benefits and reducing the willingness to adopt mixed cropping. In Europe and Germany in particular, crop rotations are largely dominated by cereal crops while grain legumes only play a minor role (e.g.,

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Fig. 1 Mixed cropping with winter wheat and winter faba bean in alternating rows

Bedoussac et al. 2015; Hart et al. 2017; Mawois et al. 2019; Meynard et al. 2018). Introducing legumes into the crop rotation, either as a sole crop or in mixed stands, therefore means that most farmers cannot rely on their own know-how since they do not have experience in the cultivation (e.g., Mawois et al. 2019). Furthermore, while it has been shown that mixed stands are efficient in low-input agricultural systems with respect to fertilization (Pelzer et al. 2012), a lack of research about the economic efficiency of mixed stands in high-input agricultural systems persists (e.g., Rosa-Schleich et al. 2019). Extensive operational knowledge that is relevant for the practical implementation by farmers is very limited, e.g., information about crop protection in mixed stands (e.g., Bedoussac et al. 2015). Similar to the case of legume cultivation, which has been described as an innovation niche opposing the dominant cereal crops (Meynard et al. 2018), the adoption of mixed cropping is therefore associated with high uncertainty for farmers and adoption is consequently low (e.g., Lemken et al. 2017).

In addition, until recently the political focus on mixed cropping in Europe and specifically Germany has been very limited, meaning that mixed cropping has had to compete with the established cereal crops in terms of profitability (e.g., Lemken et al. 2017). In Germany, mixed stands of legumes and non-legumes have been included into a nationwide political support scheme with the latest changes to regulations for ecological focus areas under the Common Agricultural Policy for the first time in 2018 (BMEL 2018). Moreover, with the upcoming reform of the Common Agricultural Policy in 2020, further changes can be expected in Germany, as well as the other European countries, increasing uncertainty for farmers and limiting the positive effects of the recent changes on mixed cropping adoption. Including mixed cropping into a subsidy scheme is however a lever to increase adoption by European farmers (e.g., Bedoussac et al. 2015).

While the implementation of regulatory restrictions and financial incentives can trigger initial adoption decisions with regard to minor crops, these measures are often not sufficient to induce long-lasting changes in production patterns by farmers (Meynard et al. 2018). If long-term behavioral changes are

desired, it is also necessary to gain an understanding of factors other than financial incentives influencing farmers' decision making. In particular, psychological factors underlying farmers' behavior have been shown to be relevant in cases of different agri-environmental related measures, since the adoption of such measures is not solely dependent on financial motives (Lokhorst et al. 2011; Mills et al. 2017). These behavioral insights can also help to guide the development of agri-environmental policies, as well as other development measures, and are considered especially relevant for the voluntary adoption of more sustainable practices (Dessart et al. 2019). Up to now, there has only been very little research on the socio-economic and behavioral aspects of mixed cropping adoption. Lemken et al. (2017) provided first insights into the characteristics of early adopters of mixed cropping in Germany. However, there is still a lack of research which could help to understand how to encourage the adoption of mixed cropping by farmers. Considering the challenges a farmer faces when introducing mixed cropping, such as the increased complexity of cultivating mixed stands, understanding the decision-making process of farmers is paramount to facilitate the adoption of mixed cropping.

Therefore, the objective of this study is twofold: First and foremost, we want to identify which and how underlying psychological factors influence a farmer's intention to adopt mixed cropping. To the best of our knowledge, this is the first study aiming to provide an in-depth understanding of the motivations behind a farmer's intention to adopt mixed cropping using the conceptual framework of the theory of planned behavior (TPB). We extended the original framework, which was first introduced by Ajzen (1985), by including social group norms and perceived ecological benefits. These proposed extensions can also be used for analyzing farmers' adoption behavior with respect to other new (sustainable) practices. Second, we want to assess which adoption obstacles are perceived as most important by the farmers since these are the ones which have to be addressed first in order to enhance widespread adoption. Though our study is based on a sample of German farmers, our results are partially transferable to other European countries with a similar structure of the agricultural sector as well. We thus aim to provide valuable insights into mechanisms that could increase mixed cropping adoption by farmers in Europe. These insights are of interest for policymakers and researchers alike, as they can help to guide the direction of future research and indicate which agri-environmental schemes would be suitable to encourage adoption.

2 Material and methods

2.1 Conceptual framework

To understand the intention of farmers to adopt mixed cropping, the theory of planned behavior (TPB) (Ajzen

1985, 1991) is utilized as the main framework (Fig. 2). The TPB has previously been used to gain insights into, for example, farmers' behavior in the context of (unsubsidized) agri-environmental measures and conservation agriculture (Greiner 2015; Reimer et al. 2012; van Dijk et al. 2016). The TPB was designed to explain and predict human behavior in specific contexts as the outcome of three central psychological constructs: attitude towards the behavior, perceived behavioral control, and subjective norm (Ajzen 1991). These constructs reflect the subjective perceptions of an individual. The behavior in our application is the adoption of mixed cropping with main crops, which represents an adoption decision related to a new and innovative farming practice. The hypotheses derived in the following and the applied extensions could also be transferred to other applications relating to the adoption of new techniques in the agricultural context.

Attitude towards the behavior is a construct that captures the individual's assessment of the behavior in question, with a positive attitude generally increasing the likelihood of performing the behavior (Ajzen 1985). Subjective norm corresponds to the social pressure to perform a specific behavior. A person is more inclined to perform a certain behavior if this behavior is deemed desirable by important others (Ajzen 1985). This type of norm is also referred to as injunctive norm, i.e., one's perception of other people's expectations (e.g., Dessart et al. 2019). For our application, this construct reflects the farmer's perception of social pressure from politics and society to adopt mixed cropping. The perceived behavioral control refers to the extent to which a person assumes a behavior to be difficult or easy to perform, i.e., in our application the perceived capability to adopt mixed cropping. These three constructs are hypothesized to motivate the intention to perform a specific behavior (Ajzen 1991). Applied to our

research context, the following three hypotheses were derived from the original TPB framework:

- H1: The farmer's attitude towards mixed cropping positively influences the farmer's intention to adopt mixed cropping.
- H2: The subjective norm perceived by the farmer positively influences the farmer's intention to adopt mixed cropping.
- H3: The farmer's perceived behavioral control positively influences the farmer's intention to adopt mixed cropping

It has been argued that instead of subjective norm as a measure for overall social pressure from important others, social pressure perceived from reference groups which are relevant for the behavior is more likely to influence the behavior (Terry et al. 1999). Based in social identity theory the TPB has therefore been extended to include injunctive group norms separately. Group norms have been shown to influence for instance farmers' intention to perform agri-environmental related measures (van Dijk et al. 2015; Werner et al. 2017). As this social pressure in the form of an injunctive norm from a particular peer group is only perceived if the individual identifies strongly with this group (Terry et al. 1999), we chose to separately include the group of farmers in our applied framework.

- H4: The injunctive group norm perceived by the farmer positively influences the farmer's intention to adopt mixed cropping

In addition to this specified injunctive group norm, it is also possible to consider descriptive norms in the context of the peer group, i.e., what the peer group actually does. A relationship to a farmer who has already adopted a specific practice can lead to the sharing of accurate information about the practice in question (Dessart et al. 2019). Since information about the cultivation of mixed stands is currently very limited, especially with regard to the associated costs and benefits for specific combinations of plant species, this line of reasoning is applicable in our case. We assume that farmers who know other farmers who have already adopted mixed cropping have a higher intention of adopting it as well, and therefore, we have included the following hypothesis:

- H5: The descriptive group norm perceived by the farmer positively influences the farmer's intention to adopt mixed cropping.

Fig. 2 Proposed extended research framework based on theory of planned behavior by Ajzen (1985, 1991). The first part of the structural model will be estimated using partial least squares structural equation modelling; the second part will be estimated with a logit model

Several extensions of the TPB have been applied in the literature to further enhance the understanding of the psychological drivers of behavior (Lokhorst et al. 2011). Among others, practice characteristics have been proposed as a potential extension to the TPB in the context of conservation agriculture adoption. Reimer et al. (2012) find

that environmental benefits of a conservation practice positively influence their adoption. Similarly, Arbuckle and Roesch-McNally (2015) include perceived benefits of cover crops into the TPB framework. While they estimate the effect on the adoption of cover crops, we assume that perceived practice characteristics affect the attitude towards the behavior as well as the behavioral intention. We thus implicitly assume an indirect and a direct effect of these practice characteristics on the intention to adopt. We further specified the practice characteristics as perceived ecological benefits making our construct very similar to that of Reimer et al. (2012) and Arbuckle and Roesch-McNally (2015). Against this background, the following hypotheses are formulated:

- H6a: The perceived ecological benefits positively influence the farmer's attitude towards mixed cropping.
 H6b: The perceived ecological benefits positively influence the farmer's intention to adopt mixed cropping.

According to the original TPB framework, two constructs directly influence the actual performance of a certain behavior: the intention to perform the behavior and the perceived behavioral control (Ajzen 1991). The intention accounts for the motivation a person has, while the perceived behavioral control refers to the ability of a person to perform the behavior in question. A person that, *ceteris paribus*, has a lower intention to perform a certain behavior is less likely to actually perform said behavior, even if that person has the ability to execute it (Ajzen 1991). A higher perceived behavioral control over a certain behavior increases the likelihood of performing such a behavior (Ajzen 1991). This line of reasoning is applicable for the adoption of mixed cropping, especially considering that mixed cropping is a new production method for most farmers. Furthermore, Lemken et al. (2017) find that technical barriers negatively influence the adoption of mixed cropping. Technical barriers can reduce the actual behavioral control. Since perceived behavioral control serves as a proxy for actual behavioral control and is of greater interest when focusing on psychological factors (Ajzen 1991), we assume that the perceived behavioral control is relevant for the actual adoption decision of mixed cropping. Consequently, the following hypotheses are formulated:

- H7: The farmer's intention to adopt mixed cropping positively influences the farmer's adoption of mixed cropping
 H8: The farmer's perceived behavioral control positively influences the farmer's adoption of mixed cropping

These psychological constructs are latent and cannot be observed directly. For this purpose, variables and formulated

statements serve as indicators for these constructs (see Tables 1 and 2).

2.2 Survey design and sample

To collect data for our research questions, we conducted an anonymous online survey with German farmers based on a structured questionnaire. At the beginning of the survey we provided a short explanation about the term "mixed cropping" in general and further specified that the questions are focused on mixed stands with (at least) two main crops. This distinction is relevant, since various forms of mixed stands are cultivated differently. While mixtures of catch crops or mixtures in green fodder production are already relatively common in the European agricultural sector (e.g., Bedoussac et al. 2015), partially due to their easy implementation, the same cannot be said for mixtures of main crops. Since our research focus is mixed stands with main crops, we made this specification clear and also provided examples of crop combinations which fulfill this definition. In this way, we ensured that all farmers considered the same specification of mixed stands while answering the questions in order to establish internal validity.

The first part of the questionnaire contained statements to capture the constructs of the TPB which were formulated as direct measurements in accordance with the literature and adapted to the context of mixed cropping. These indicators were measured on 5-point Likert-scales, ranging from 1 = "totally disagree" up to 5 = "totally agree" (all used indicators can be found in Table 2). These statements were presented to the farmers in a randomized order to avoid a potential order effect.

The main focus of this study is to gain a better understanding of psychological factors underlying farmers' behavioral intentions toward mixed cropping which reflects the farmers' willingness to adopt. Another main driver that affects production choices of farmers is their ability to adopt, which refers to external factors (Mills et al. 2017). In general terms, this relates to farm characteristics and the external conditions in which the farmer operates. Bedoussac et al. (2015) emphasized that there are practical questions that might hinder adoption. Our applied framework and the statements used for the TPB partly capture technical barriers through the construct of perceived behavioral control (see Table 2). Nevertheless, considering the low adoption of mixed cropping in Germany and in the EU and the many challenges a farmer faces when adopting mixed cropping as outlined in the Introduction, there are a number of adoption obstacles which cannot all be captured through the factors included in the TPB. Thus, to gather first explorative insights and as a possible starting point for further research into farmers' ability to adopt mixed cropping we have addressed adoption obstacles related to mixed cropping separately. Similar to Zimmer et al. (2016), who showed Luxembourgish farmers' responses with respect to

Table 1 Descriptive sample statistics and results for mixed cropping adoption and descriptive group norm ($N=172$)

Variable	Mean/ Share	SD	German Average ^a
Adoption of Mixed Cropping (with main crops)	13.37%		n.a.
Descriptive group norm (know farmers that adopted mixed cropping)	50.58%		n.a.
Age (in years)			
<25	12.21%		8%
25-34	40.12%		16%
35-44	22.67%		15%
45-54	13.95%		27%
>54	11.05%		36%
College degree (at least B.Sc.)	59.88%		12%
Farm size (ha of total land managed)	297.58	449.07	62.4
Full-time farm	91.28%		48%
Legumes (Legume cultivation as main crop)	36.05%		n.a.
Organic farm	15.70%		12%
Region			
North (% of farms in ... states)	43.60%		20%
East	11.63%		7%
West	21.51%		24%
South	23.26%		48%
Rented land (% rented land of total land managed)	53.91%	25.00	59%
Training enterprise	73.84%		n.a.

n.a. not available

^a Source: The German Farmers' Association 2020

the need of further information and research related to legume cultivation, we presented the farmers with a list of nine prominent obstacles associated with mixed cropping (see Fig. 5). While the detailed categories they used are in principle mostly transferable to mixed cropping, we chose to reduce the categories, i.e., potential obstacles, to provide a more general overview for mixed cropping and chose to focus on those challenges which have also been discussed in the literature related to mixed cropping (Bedoussac et al. 2015; Hauggaard-Nielsen et al. 2008; Lemken et al. 2017; Pelzer et al. 2012). Therefore, in our questionnaire the farmers were made to choose up to five out of the nine presented obstacles they saw as the most important. This form of questions allows us to derive a ranking of the most crucial obstacles from a practical point of view. The final parts of the survey addressed farm information and sociodemographic characteristics of the farmers.

After pre-testing the questionnaire to ensure clarity of statements, the survey was conducted between September and November 2018. The link to the survey was distributed per mail directly among agricultural training enterprises and over social media networks. The questions could be answered in about 15 min. The removal of incomplete surveys resulted in a final sample size of 172 German farmers on which our analysis is based.

Full time farmers make up 91.28% of our sample, which partly explains the relatively large average farm size of 297 ha (Table 1). Overall, comparatively young, well-educated

farmers who work full time on large farms are overrepresented in our sample compared with the national average (The German Farmers' Association 2020). A share of 73.84% of farmers classified their farm as a training enterprise, which means these farmers are responsible for the education of the next generation of farmers. Since our sample has a large share of full time farms and only these are eligible to become training enterprises, it can be inferred that training enterprises are likewise overrepresented.

Approximately half of the surveyed 172 farmers (50.58%) know a farmer who has already adopted mixed cropping with (at least) two main crops, which serves as the indicator for descriptive group norm in our structural model. A total of 13.37% of the farmers in our sample have currently included mixed stands in their crop rotation. This share is a little higher than the share Lemken et al. (2017) found in their sample of German farmers in 2016, using a similar specification of mixed stands. Only 36.05% of the farmers currently have legumes in pure stands as main crops included in their crop rotation, indicating that legume cultivation itself also faces challenges which is emphasized by Mawois et al. (2019).

2.3 Measurement model

The first part of the extended TPB model including the intention to adopt mixed cropping is estimated using partial least squares structural equation modeling (PLS-

Table 2 Descriptive results for applied indicators and outer model evaluation ($N = 172$; cutoff levels: composite reliability (CR) = 0.7–0.9; average variance extracted (AVE) > 0.5; outer loadings > 0.7)

Construct	Statement	Mean (SD)	Outer loading ^a
Attitude towards mixed cropping (CR = 0.881 AVE = 0.651)			
	I think that the cultivation of mixed stands offers many advantages	3.06 (0.97)	0.846***
	The cultivation of mixed stands is important for sustainable production	3.13 (1.10)	0.847***
	I think that economic importance of mixed cropping is going to increase in the future	3.39 (1.01)	0.819***
	I think the cultivation of mixed stands will not play an important role in the agricultural production in the future ^b	3.24 (1.21)	0.708***
Perceived behavioral control (CR = 0.788 AVE = 0.553)			
	I have the necessary knowledge to cultivate mixed stands	2.97 (1.14)	0.760***
	I have the technical capacity to cultivate mixed stands	2.92 (1.29)	0.735***
	I have the possibility to market the mixed yields	2.29 (1.17)	0.736***
Subjective Norm (CR = 0.858 AVE = 0.752)			
	Sustainable production methods like mixed cropping are increasingly in the political focus and their adoption is expected	3.48 (1.04)	0.812***
	Society expects production methods like mixed cropping which are in harmony with nature	3.44 (1.19)	0.919***
Injunctive Group Norm (CR = n.a. AVE = n.a.)			
	My farming friends, who are important to me, think that mixed stands are advantageous compared with pure stands	2.46 (1.06)	n.a.
Perceived Ecological Benefits (CR = 0.861 AVE = 0.673)			
	Mixed cropping positively affects biological diversity	4.34 (0.83)	0.838***
	Mixed stands can contribute to the preservation and improvement of soil quality	4.28 (0.82)	0.794***
	The water and nutrient utilization is improved in mixed stands	3.70 (0.94)	0.829***
Intention to adopt mixed cropping (CR = 0.889 AVE = 0.800)			
	I intend to integrate mixed stands into my crop rotation	2.64 (1.25)	0.925***
	I will not cultivate mixed stands in the future ^b	3.20 (1.32)	0.863***

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

^b Numerical coding for negatively formulated statements was reversed to establish equal coding for estimation

SEM). Subsequently, a logit model for the actual adoption decision is estimated to account for the binary response structure regarding the adoption of mixed cropping (see Fig. 2).

PLS-SEM is a nonparametric variance-based approach which aims to maximize the explained variance of the endogenous variables (Hair et al. 2017). Our objective is to identify the key influencing factors on our target construct, which Sarstedt et al. (2017) emphasize as a valid reason to use the PLS-SEM approach. The use of latent variables scores in the subsequent analysis, in our case a logit model, further justifies this approach (Sarstedt et al. 2017). In addition, PLS-SEM allows the use of constructs with only one or two indicators and is also suitable for data that are not normally distributed (Hair et al. 2017).

PLS-SEM allows for the simultaneous estimation of the outer model, i.e., the outer loadings of measured indicators on the latent construct, and the inner model, i.e., the path coefficients between the latent constructs. All included constructs are defined as reflective measurements, assuming

that the applied indicators are a sample of possible items that stem from the same conceptual domain and that co-variation between the indicators of one construct is caused by the underlying latent construct. For reflective measurement models, the relationship is from the latent construct to its measured indicator variables and measurement errors are accounted for at the indicator level (Hair et al. 2017; Jarvis et al. 2003). Formally, a reflective outer model for an exogenous latent construct ξ can be specified as

$$x = \lambda_x \xi + \varepsilon_x \quad (1)$$

where x is a vector of the measured indicator variables and λ_x is a vector of (outer) loadings. ε_x is an error term which accounts for unobserved variance. Similarly, a reflective outer model for an endogenous latent construct can be denoted as

$$y = \lambda_y \eta + \varepsilon_y \quad (2)$$

where y is a vector of the measured indicator variables, λ_y a vector of (outer) loadings, and ε_y is the error term that accounts for unobserved variance. In PLS-SEM “endogenous” refers to those constructs which are aimed to be explained by the inner (structural) model, i.e., that have paths leading towards them. In our applied structural model, the constructs for attitude and intention are endogenous, while all other constructs are exogenous. The inner model, which estimates the path coefficients between exogenous constructs and the endogenous constructs or between two endogenous constructs can then be specified as follows:

$$\eta = B\eta + \Gamma\xi + \zeta \quad (3)$$

with η representing the vector of endogenous constructs. B and Γ are path coefficient matrices for the causal effects from the respective endogenous constructs η and exogenous constructs ξ . These estimated path coefficients can be interpreted as standardized beta coefficients. The residuals for the inner model are depicted by the ζ (Chin 1998; Dijkstra 2010; Hair et al. 2017). The iterative PLS algorithm first estimates scores for the latent constructs and subsequently the loadings and the structural models path coefficients in the second stage (Hair et al. 2017; Henseler 2010). Figure 3 depicts the relations of the formulas (1) to (3) graphically.

According to Hair et al. (2017), the evaluation of the PLS-SEM results is carried out in two consecutive steps: The evaluation of the outer model subsequently followed by the inner model evaluation. The outer model

Fig. 3 Illustration of formal relations between inner and outer model, as well as between indicator variables (x, y) and constructs (ξ, η). Depicted as an exemplary extract from the applied model: perceived behavioral control (ξ) is exogenous with associated indicator statements (pb1-3; see Table 2). Intention (η) is endogenous with associated indicator statements (int1-2). Illustration based on Chin (1998)

assessment includes the evaluation of the reflective constructs with regard to internal consistency reliability, indicator reliability, convergent validity, and discriminant validity. Composite reliability is a measure for the internal consistency reliability, for which values between at least 0.7 and 0.9 are acceptable. Indicator reliability is related to the extent of an indicator's variance which the construct can explain. It is established if the outer loadings of the indicators are significant and their value exceeds the benchmark of 0.708. Convergent validity also refers to the extent to which a latent construct explains each indicator's variance and can be assessed through the average variance extracted. The average variance extracted should be above the cut-off level of 0.5, meaning that the variance captured between constructs and the corresponding indicators surpasses variance due to measurement errors. In order to evaluate the discriminant validity, the heterotrait-monotrait ratios can be used. Values should be below the benchmark of 0.850 to ensure that constructs are separable from each other. To account for possible multicollinearity issues, which would bias the path coefficients, the variance inflation factors can be estimated. The values for this criterion should be below five (Hair et al. 2017).

The evaluation of the inner model, i.e., the structural model, includes the estimation of the explained variance (R^2) and the out-of-sample predictive relevance (Stone-Geisser- Q^2). The Stone-Geisser- Q^2 is calculated based on the blindfolding technique with an omission distance of 10. Since PLS-SEM is a non-parametric estimation method, it is necessary to apply a re-sample bootstrapping procedure to allow for the testing of hypotheses. We followed the recommendation of Hair et al. (2017) and applied 5000 bootstrap samples to generate t statistics.

Hair et al. (2012) stress that the PLS-SEM should not be used for an endogenous construct based on a single binary indicator, as the algorithm is based on ordinary least squares. Since the initial decision to adopt mixed cropping is a choice situation with a binary outcome, to adopt or not, PLS-SEM is not suitable in this case. We therefore estimated additional logit models based on maximum likelihood estimation for the adoption decision, assuming a logistic distribution of the error term ε . The latent factors scores for the intention to adopt mixed cropping ($\hat{\eta}_{\text{Intention}_i}$) and the perceived behavioral control ($\hat{\xi}_{\text{PBC}_i}$), which were established through the PLS-SEM, were included as the independent explanatory variables. Formally, the adoption decision is then specified as

$$y = \begin{cases} 1 & \text{if Adoption} > 0 \\ 0 & \text{if Adoption} = 0 \end{cases} \quad (4)$$

$$\text{Adoption}_i = \beta_0 + \beta_1 \hat{\eta}_{\text{Intention}_i} + \beta_2 \hat{\xi}_{\text{PBC}_i} + \varepsilon_i \quad (5)$$

where i represents the individual respondent and ε_i is assumed to be a random error term. As an extension we also estimated a logit model which includes a set of farm and farmer related control variables (see Table 1) in addition to the factors scores and is specified as follows:

$$\begin{aligned} \text{Adoption}_i = & \beta_0 + \beta_1 \hat{\eta}_{\text{Intention}_i} + \beta_2 \hat{\xi}_{\text{PBC}_i} + \beta_3 \text{Age}_i \\ & + \beta_4 \text{College degree}_i + \beta_5 \text{Farm size}_i \\ & + \beta_6 \text{Fulltime}_i + \beta_7 \text{Legumes}_i + \beta_8 \text{Organic}_i \\ & + \beta_9 \text{Rented land}_i + \beta_{10} \text{Training enter}_i + \varepsilon_i \quad (6) \end{aligned}$$

To validate the models, several specification tests were applied and their results are displayed in the results section. Statistical analysis and model estimation was conducted with Stata 15 and SmartPLS 3 (Ringle et al. 2015).

3 Results and discussion

3.1 Evaluation of the outer model and descriptive indicator results

To evaluate the quality of the measurement model, we followed the sequence described by Hair et al. (2017): Composite reliability is above the cut-off level of 0.7 for all of our reflective constructs (Table 2), thus implying that internal consistency reliability is given in our model. The outer loadings of the indicators are all statistically significant at the 1% level, and their values all exceed the benchmark of 0.7, establishing the indicator reliability in our model. The values for average variance extracted surpass the benchmark of 0.5 in all cases. The heterotrait-monotrait ratios were calculated to assess the discriminant validity. With a maximum value of 0.796 for our model, we assume that discriminant validity is given, since the benchmark of 0.850 is not exceeded. With a maximum variance inflation factor of 1.996 it can also be assumed that no multicollinearity issues are present in our model. Hence, the validity of the outer model is given.

The descriptive results for the applied indicators offer some interesting insights. Mean values for perceived behavioral control indicators tend towards partial disagreement, implying that farmers see difficulties associated with the cultivation of mixed stands. The indicators for subjective norm, i.e., the perceived pressure from politics and society at larger, tends, on average, towards partial agreement. Since there has only been limited political focus on mixed cropping, these results

are plausible. In contrast, group norm, i.e., perceived pressure from the peer group of other farmers, has a mean value tending towards “partially disagree.” This indicates that mixed cropping is not viewed in a very positive light within the group of farmers. Nevertheless, the indicator for descriptive group norm shows that approximately half of the surveyed farmers know a farmer who has adopted mixed cropping (Table 1).

3.2 Evaluation of the inner model and estimation results

The estimated structural model for the TPB explains 52.4% of the variance in the intention to adopt mixed cropping. The predictive relevance of the model was evaluated using the Stone-Geisser- Q^2 , which has a value of 38.30% for the intention. The results show that the attitude towards mixed cropping has the strongest path coefficient towards intention among the constructs included in the estimated model and is statistically significant (Fig. 4). Consequently, H1 is supported. This result is in line with previous research which has shown that attitude is among the most influential factors affecting the intention to perform agri-environmental measures (Greiner 2015). This result also confirms the results of Lemken et al. (2017) regarding the role of farmers’ attitudes in the adoption of mixed cropping. The model also confirms that a higher perceived behavioral control increases the intention at the 1% level of significance. The applied indicators for this construct referred inter alia to marketing and technical capabilities. Considering that the descriptive results for these indicators all tended towards partial disagreement, implying challenges in these areas, this emphasizes the need for technical advancement and marketing possibilities in order to increase mixed cropping adoption.

The injunctive group norm, i.e., perceived social pressure from other farmers, has a positive and statistically significant effect on the intention, as expected (H4). In contrast, perceived social pressure from politics and society has a slightly negative effect on the intention to adopt, although not statistically significant (H2). This result is in contrast to the TPB, as a positive effect is assumed. Our results are also in contrast to some previous applications of the TPB in the agricultural domain. For example, van Dijk et al. (2016) find statistically significant and positive effects of subjective norm on the intention to perform agri-environmental measures. However, our measurement of subjective norm, i.e., the applied indicators, differs from these studies. Often the subjective norm is conceptualized referring to overall social pressure perceived from significant others, e.g., “People who are important to me (...)” (e.g., Werner et al. 2017). In contrast to that we differentiated the injunctive norms between social pressure from politics, society, and other farmers. The separation of these indicators into two distinct constructs is in line with previous

Fig. 4 PLS-SEM inner model results for the intention to adopt mixed cropping. Asterisks indicate different levels of significance for *t* tests based on bootstrapping with 5000 runs (*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$)

research which explicitly included social identity theory into the TPB, applying group norm and subjective norm separately, and allowed a more comprehensive understanding regarding the sources of perceived social pressure (Fielding et al. 2008; van Dijk et al. 2015; Werner et al. 2017). While measuring group norms with respect to a specific group, subjective norm was measured with reference to important others in these studies. The attitude of other farmers in our study is classified as group norm, since farmers can be seen as a reference group in terms of agricultural practices. As Fielding et al. (2008) emphasize, considering social identity theory, the norms of a group which includes the respondent are likely to influence his or her behavior. The distinction between in-group and out-group norms can explain the different results our model shows for subjective norm and injunctive group norm. Resistance against the out-group norms, i.e., expectations from politics and society in our case, can indicate protest against the predominant power of the outer group (Fielding et al. 2008). While our results only suggest a very slightly negative influence of subjective norm on the intention to adopt mixed cropping, which is not statistically significant, they support this line of reasoning. Increasing political and societal pressure to increase the adoption of mixed cropping might not be effective, since farmers may show a defiant reaction if mandatory restrictions are implemented. Trying to enforce the adoption of mixed cropping could lead to a subjective deterioration of the farmers' attitude, which could negatively influence the voluntary intention to adopt mixed cropping as a form of reactance (Miron and Brehm 2006). In order to avoid a negative effect of a political intervention by the described

resistance against out-group norms, a voluntary agri-environmental scheme seems to be a suitable possibility to encourage adoption. Furthermore, our results highlight the importance of distinguishing social norms between different groups as the effects of social norms in our model between in- and out-group norms differ.

In addition, our results show that the descriptive group norm also has a statistically positive effect on the intention, as was postulated in H5. The path coefficient is even stronger than that of the injunctive group norm, indicating that in the case of mixed cropping it is of greater relevance what the other farmers actually do. As Dessart et al. (2019) note, this could be due to the fact that contact with farmers who have already adopted a specific practice enables the gathering of information which is otherwise not obtained. In case of mixed cropping, there are many uncertainties to adoption, as this practice can be considered quite innovative compared with the status quo farming methods. Contact with farmers who have already adopted this practice and have practical experience applying it can reduce this uncertainty. This result is also in line with the results of Mawois et al. (2019) which showed that informal networks are important for the adoption of legumes, in cases where information about cultivation is scarce. Similarly, Cholez et al. (2020) show the relevance of contractual networks for developing new knowledge for marginalized production practices. Seeing other farmers implement a practice can motivate more farmers to do the same (Dessart et al. 2019). To facilitate the widespread adoption of mixed cropping, it is therefore beneficial to encourage the early adopters, which could also be supported by the implementation of voluntary agri-environmental schemes. The positive and significant path coefficients for both applied group norms (descriptive and injunctive) also imply that the effects of interactions between farmers should be considered within policy schemes to utilize the facilitating effect these group norms can have on the intention and ultimately the adoption of new sustainable practices. Contributing to the limited empirical evidence on the effects of group norms on the adoption of sustainable practices, these results also support previous findings on the relevance of spatial proximity for the adoption of new sustainable practices and the associated informal knowledge sharing (Banerjee et al. 2017; Läßle and van Rensburg 2011)

As was hypothesized, our additional construct has positive path coefficients towards the attitude and intention. The effect on the intention is only very slightly positive and not statistically significant; hence, H6b cannot be supported. We conducted a mediation analysis to test for the significance of the indirect effect of "perceived ecological benefits" via the attitude towards the intention, as the sequence of the two direct effects (H6a and H1). This indirect effect, which is the product of the successive path coefficients ($0.143 = 0.298 \times 0.479$), is statistically significant with $p = 0.011$. The significant indirect effect and the

insignificant direct effect (H6b) can be classified as indirect-only mediation (Hair et al. 2017; Zhao et al. 2010). This implies that the attitude fully mediates the perceived ecological benefits to intention relationship; i.e., the ecological benefits lead to a higher attitude which in turn leads to a higher intention. This result is in line with prior research which suggests that practice characteristics influence the adoption behavior of farmers (Arbuckle and Roesch-McNally 2015). Furthermore, it emphasizes that farmers value cultivation methods which are ecologically sustainable, as Reimer et al. (2012) also show for conservation practices. However, the non-significant effect on the intention to adopt mixed cropping also indicates that these ecological benefits are not sufficient to directly influence intention and thus the behavior. Therefore, it might be beneficial to account for further practices characteristics, like associated risks, in future research.

In order to assess factors influencing the actual adoption of mixed cropping, we estimated two logit models including the factor scores estimated through the PLS-SEM for the latent variables which are standardized with a mean of 0 and a standard deviation of 1. According to the TPB the “intention” (min − 1.636; max 1.850) and “perceived behavioral control” (min − 1.912; max 2.605) were included. Model 1 only uses the factor scores as exogenous variables and displays a good model fit. A classification test showed that the model correctly classifies 90.12% of the responses (Table 3).

As was postulated by the TPB, we can support H7 that the intention to adopt mixed cropping is a strong indicator for the actual adoption behavior. The odds ratio for intention is significant at the 1% level. With an odds ratio far larger than 1, the positive effect of intention on the adoption is considerable.

Our model shows no statistically significant effect of perceived behavioral control on the adoption of mixed cropping (H8, $p = 0.128$). However, the direction of the effect is positive as hypothesized. A possible explanation for this finding could be that farmers are not familiar enough with the practice characteristics of mixed cropping, and therefore, the measured items are not accurate enough to capture the actual behavioral control (Ajzen 1991). Van Dijk et al. (2016) also did not find a statistically significant effect for the perceived behavioral control to adopt agri-environmental measures, while the effect was significant on the intention. In contrast, Fielding et al. (2008) report a statistically significant effect of perceived behavioral control on the behavior and on the intention for the implementation of sustainable agricultural practices.

Model 2 includes farm and farmer related characteristics as an extension of Model 1. The model performs slightly better in terms of the specification tests; however, comparing the pseudo R^2 values the improvements are not substantial, emphasizing the relevance of the psychological factors. Among these control variables we only find a statistically significant effect for “Organic farm” which indicates that organic farmers are more likely to adopt mixed cropping. Considering that mixed cropping seems to perform well under low-input conditions (Pelzer et al. 2012) and that organic yields are usually much lower than conventionally produced yields, this result is plausible. In addition, organic farms receive higher product prices and more subsidy payments per hectare, which can reduce the relevance of uncertainty effects related to mixed cropping adoption. With the exception of the variable “Legumes,” our results confirm the ones of Lemken et al.

Table 3 Logistic regression results $N = 172$

Adoption of Mixed Cropping	Model 1		Model 2	
	Odds Ratio	z-statistic	Odds Ratio	z-statistic
Intention (H7)	8.7848*** ^a	4.32	9.1797***	3.61
Perceived behavioral control (H8)	1.6016	1.46	1.4466	0.99
Age			0.9609	− 1.10
College degree			0.9094	− 0.13
Farm size (ha)			0.9994	− 0.50
Full-time farm			4.0214	1.10
Legumes			1.9299	0.95
Organic farm			4.1406**	1.97
Rented land			0.9911	− 0.62
Training enterprise			0.3004	− 1.13
Log-likelihood	− 37.839575		− 33.039214	
LR χ^2	$\chi^2(2) = 59.56$ ($p = 0.000$)		$\chi^2(10) = 69.25$ ($p = 0.000$)	
Pseudo R^2	0.4408		0.5117	
Hosmer-Lemeshow $\chi^2(8)$	2.80 ($p = 0.9465$)		5.68 ($p = 0.6832$)	
Max. variance inflation factor	1.29		1.65	

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

(2017), who also did not find statistically significant effects for farmer and farm-related characteristics. These results jointly imply that willingness to adopt is more important than the external factors related to the farm and farmer for the adoption of mixed cropping.

3.3 Obstacles for the adoption of mixed cropping

Presented with a list of nine obstacles for the practical implementation of mixed cropping, around 95% of the respondents chose the maximum number of five obstacles (Fig. 5). According to our results, missing sales opportunities for mixed yields is the most crucial obstacle for the practical realization of mixed cropping, from the perspective of adopters and non-adopters. In contrast to pure stands, a combined yield of legumes and cereals requires additional steps to separate the harvest. While an on-farm use of the mixed yields as fodder is possible under certain circumstances, the marketing of mixed yields seems to be problematic and processing mixed yields can be difficult. Technology to sort the grains of mixed yields is in principle readily available, but the sorting of grains is an additional step in the process which is also associated with higher costs (Loïc et al. 2018). This is interrelated with the farmers' perception that the economic benefits of mixed cropping are not sufficient. Considering additional costs for grain sorting, but also learning costs due to the innovative character of mixed stands for many farmers, economic benefits are also a major concern of the non-adopters farmers in our sample.

The perception of insufficient economic benefits as one of the most crucial obstacles indicates that financial incentives could facilitate adoption in the short run. In the long run, however, productivity of mixed stands has to be increased, which emphasizes the need for further agronomic research. While it has been shown that mixed stands can produce higher yields compared with their corresponding pure stands, these results are often

produced under low-input fertilization conditions (e.g., Pelzer et al. 2012). As the European agricultural sector usually works under high-input conditions, those results are not completely transferrable. Furthermore, there is a lack of research related to the economic efficiency of mixed cropping (Rosa-Schleich et al. 2019). While there are some examples of studies that conclude mixed stands have higher gross margins compared with their corresponding pure stands (Bedoussac et al. 2015; Loïc et al. 2018; Pelzer et al. 2012), these studies often assume prices for organically produced grains or compare gross margins under low-input conditions using results from scientific field trials. Those benchmarks are not necessarily suitable to draw unambiguous conclusions about the economic advantages of mixed cropping for the conventional agricultural sector.

The uneven maturing of crops in mixed stands is also ranked among the top obstacles for the adoption of mixed cropping for both adopters and non-adopters. If crops do not mature evenly in mixed stands, yield losses are inevitable, which in turn can decrease the farmer's revenue. This indicates a need for further research in agronomy and plant breeding to provide combinations of varieties which are suitable to cultivate in mixed stands. Or in cases where suitable varieties already exist, a better communication of research results to farmers and increased marketing activities are necessary, to make farmers aware of the possibilities. Crop protection can also be challenging in mixed stands. It has been shown that mixed stands can promote biological pest management (Wezel et al. 2014). However, the applicability of herbicides is restricted in mixed stands, which requires an adjustment of crop protection practices by the farmers towards mechanical crop protection. While mechanical crop protection is possible in mixed stands, non-adopters consider this among the most crucial obstacles to adoption, which indicates that knowledge regarding such practices should be better communicated to potential users, especially considering that the adopters do not rank this obstacle that high. In contrast

Fig. 5 Responses regarding obstacles perceived as most important for the practical implementation of mixed cropping by non-adopters ($N = 149$) and adopters ($N = 23$). Respondents could choose up to five of the nine different obstacles; 95% chose the maximum number of obstacles

to the non-adopters, adopters of mixed cropping rank insufficient knowledge about the cultivation and missing expert advice considerably higher. On the one hand, this indicates that some challenges and obstacles become more apparent and relevant after adoption takes place. On the other hand, this also points to the relevance of knowledge sharing and development for marginalized products (Cholez et al. 2020).

Meynard et al. (2018) show that a socio-technological lock-in hinders the development, and consequently the adoption of minor crops in France. They highlight that obstacles are present along each step in the value chain. Considering that grain legume cultivation in Europe faces many challenges (Mawois et al. 2019), and that mixed stands with legumes are a further specialized production method, it is not surprising that the effects of the technological lock-in seem to be even more pronounced. Our results show for the first time which challenges along the value chain, from plant breeding to the processing firms, are perceived as most crucial by farmers in Germany with respect to mixed cropping and therefore should be addressed as such. In order to facilitate widespread adoption, it will be necessary to include actors along the value chain, which Meynard et al. (2018) also pointed out for minor crops. Considering the increased research interest in mixed cropping in the recent past (e.g., Martin-Guay et al. 2018) and its possible contribution towards sustainable intensification, our results also indicate that it is important to improve knowledge transfer between researchers and farmers.

Overall, our results show that the attitude towards mixed cropping has the strongest effect on the intention, which in turn is a strong indicator for the actual adoption. We also show that social group norms positively influence farmer's intention to adopt mixed cropping. These results jointly suggest that the farmers' willingness to adopt is a strong predictor for the actual adoption decision and that one lever to increase their willingness is to utilize positive effects of social group norms. If the willingness to adopt is high, farmers will adopt mixed cropping despite the outlined obstacles. This also underscores the relevance of including farmers as early as possible into current research efforts, in order to encourage early adoption and the associated increased awareness of mixed cropping among farmers. Our results also imply that it would be beneficial to include mixed cropping into voluntary agri-environmental schemes on national levels to encourage adoption of mixed cropping in Germany, and possibly in other European countries. Utilizing the positive effects of group norms within a policy scheme could further enhance adoption.

4 Conclusion

Mixed cropping can contribute towards the sustainable intensification of agriculture by diversifying cropping systems and preserving biodiversity. Nevertheless, the advantages associated with

mixed cropping are often accompanied by associated challenges from a farmer's point of view, and research related to factors influencing the adoption decision is scarce. Therefore, this study provides first detailed insights into psychological factors that motivate farmers' intention to adopt mixed cropping assessing the farmers' willingness to adopt. Applying an extended version of the theory of planned behavior has allowed us to identify attitude, perceived behavioral control, and the injunctive and descriptive group norms as major determinants of the intention to adopt mixed cropping. Here we show for the first time that social group norms have a strong effect on the intention to adopt mixed cropping. This insight can be used to guide the direction of future efforts to encourage widespread adoption, for instance by promoting an improved knowledge transfer between scientists and practitioners as well as between early adopters and non-adopters of mixed cropping. Furthermore, we found that perceived ecological benefits positively influence farmers' attitudes towards mixed cropping. This suggests that farmers want to incorporate more sustainable practices and that practice characteristics are relevant in the decision making process of farmers. The applied model extensions can be transferred to the adoption of other sustainable practices and especially the consideration of group norms can offer additional insights. Overall adoption of mixed cropping is still low in our sample of German farmers, but the intention to adopt can explain a substantial amount of the actual adoption behavior, supporting the theory of planned behavior. Our results emphasize the pertinence of psychological factors for the intention to adopt mixed cropping, indicating that the adoption of this sustainable practice is not solely dependent on economic reasoning and that the willingness to adopt is especially relevant for this case.

However, as the identified obstacles indicate, insufficient economic benefits are a major hurdle that hinders widespread adoption by German farmers, which supports the relevance of an agri-environmental scheme to increase adoption of mixed cropping. Voluntary schemes to support the expansion seem to be preferable in the case of mixed cropping and would also help to increase the visibility of mixed cropping advantages under on-farm conditions, which in turn would further encourage adoption according to our results regarding the positive effects of social group norms. These positive effects of group norms also indicate the relevance of designing policy schemes that enable and support knowledge transfer between farmers, especially for new sustainable practices for which practical knowledge is limited. The upcoming reform of the Common Agricultural Policy and the proposed voluntary eco-schemes (e.g., Dessart et al. 2019) might offer a suitable platform to include mixed cropping into a political support scheme to encourage adoption by farmers in the European Union.

Overall, the obstacles perceived as most important indicate the prevalence of a technological lock-in along the value chain. In order to facilitate widespread adoption it is therefore necessary to also address stakeholders along the entire value chain

(Meynard et al. 2018) and further support research. Since our results, based on the sample of German farmers, are very similar to the findings of Meynard et al. (2018) with regards to the technological lock-in for minor crops in France, it can be assumed that other European countries face similar difficulties. While our study focused on the psychological factors underlying farmers' intention to adopt, assessing farmers' willingness to adopt, further research could include further external factors, to evaluate farmers' ability to adopt (Mills et al. 2017).

Compliance with ethical standards

Data availability The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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Authors' contribution Conceptualization, V.B. and O.M.; methodology, V.B. and O.M.; formal analysis, V.B.; investigation, V.B.; writing—original draft, V.B. and O.M.; writing—review and editing, V.B. and O.M.; visualization, V.B.; Funding Acquisition, O.M.; Supervision, O.M.

Ethics approval The ethics committee of the University of Göttingen has no objections to the publication of the results of this study.

Consent to participate The survey on which this study is based was anonymous. Participation in the survey was exclusively on a voluntary basis.

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