Understanding German farmer's intention to adopt mixed cropping systems using the Theory of Planned Behavior framework

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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, the simultaneous cultivation of two or more coexisting crops in one field, 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 famers' motivation to adopt mixed cropping and which obstacles they perceive as important. 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 actors along the value chain have to be addressed in order to 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. With a growing world population and limited land resources, an increase in agricultural land productivity is imperative to ensure food security. 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) (figure 1). Reduced requirements for synthetic fertilizers, improved water use efficiency, decreased nitrogen leaching and increased biodiversity are some examples of the advantages associated with mixed stands (e.g., Gaba et al. 2015).

Figure 1: Mixed cropping with winter wheat and winter faba bean in alternating rows

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 in current production systems (e.g., 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 aspects (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). While this first inclusion of mixed cropping into an environmental scheme can encourage adoption by farmers, effects are still limited due to the recent nature of the changes. 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 (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, 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. 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 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 (figure 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). 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 (e.g., Dessart et al. 2019). In order to explain behaviors which are not exclusively subject to the control of the person, perceived behavioral control was included in the TPB as an extension of its predecessor, the Theory of Reasoned Action. The perceived behavioral control refers to the extent to which a person assumes a behavior to be difficult or easy to perform. 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 attitude towards mixed cropping positively influences the farmer's intention to adopt mixed cropping

H2: The perceived behavioral control positively influences the farmer's intention to adopt mixed cropping

H3: The subjective norm 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 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 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 regards 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 positively influences the farmer's intention to adopt mixed cropping

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 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

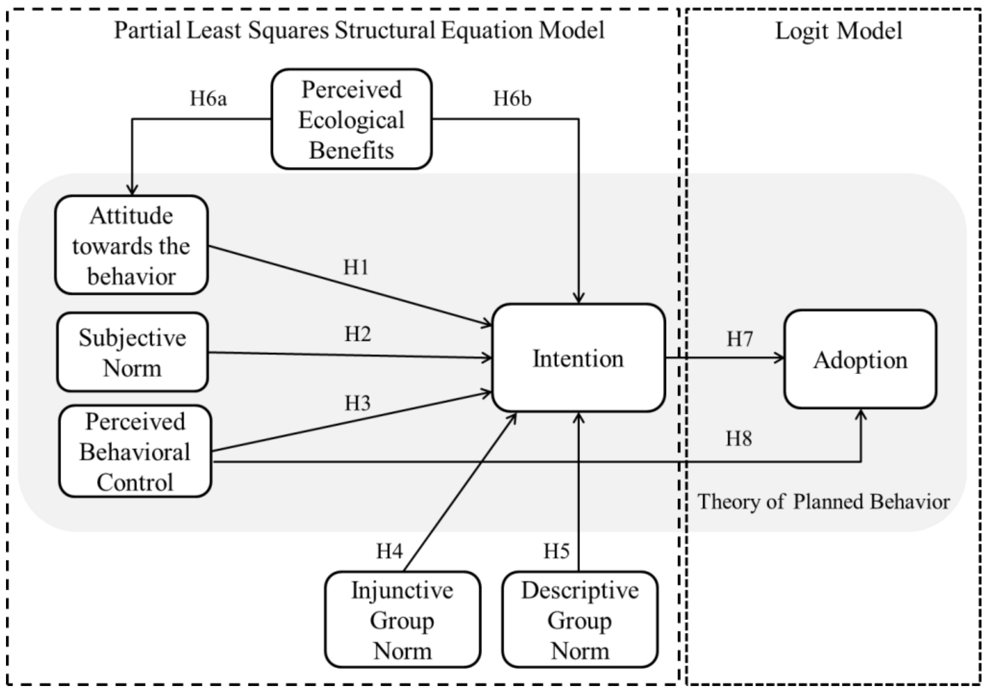

Figure 2: Proposed extended research framework based on Theory of Planned Behavior by Ajzen (1985; 1991). The first part of the structural model will be estimated using partial least squares structural equation modelling, the second part will be estimated with a logit model.

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 intention to adopt mixed cropping positively influences the adoption of mixed cropping

H8: The perceived behavioral control positively influences the adoption of mixed cropping

2.2 Survey design and sample

To collect data for our research questions, we conducted an 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 different forms of mixed stands can face different (adoption) challenges. 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". Other survey elements addressed the obstacles of mixed cropping. Lemken et al. (2017) found that technical barriers negatively influence German farmers' mixed cropping adoption tendencies significantly. Our applied framework and the used statements for the TPB partly capture technical barriers through the construct of perceived behavioral control. However, considering the relevance of these potential adoption barriers, we wanted to gain an extended insight and provide further more detailed ranking of these obstacles. For this purpose, we presented the farmers a list of nine prominent obstacles, which have been identified through a review of literature, based on both scientific and applied agricultural literature with respect to mixed cropping and legume cultivation. The farmers could choose up to five obstacles which they perceived as most crucial for the practical adoption of mixed cropping. The final parts of the survey addressed farm information and sociodemographic characteristics of the farmers.

Variable		Mean/ Share	SD
Adoption of mixed cropping (with main crops)		13.37%	
Descriptive group norm (know farmers that adopted mixed cropping)		50.58%	
Age (in years)		36.96	11.43
College degree (at least B.Sc.)		59.88%	
Farm size (ha of total land managed)		297.58	449.07
Full-time farm		91.28%	
Legumes (Legume cultivation as main crop)		36.05%	
Organic farm		15.70%	
Region	North (% of farms in ... states)	43.60%	
	East	11.63%	
	West	21.51%	
	South	23.26%	
Rented land (% rented land of total land managed)		53.91%	25.00
Training enterprise		73.84%	

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

The survey was conducted between September and November 2018. The link to the survey was distributed over social media networks. 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). As the large standard deviation for this variable indicates, we have a proportion of very large farms in our sample, which is not representative for the average German farm. 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. This observation may be especially relevant since these farmers are also likely to share their opinions on mixed cropping and thus influence the next generation.

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-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 (1=adopted, 0=not adopted) (see figure 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, this approach 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. For reflective measurement models, which are commonly used to test theories, the causal relationship is from the latent construct to its measured indicators variables (Hair et al. 2017). Formally a reflective outer model for an exogenous latent construct ξ can be specified as:

$$x = \lambda_x \xi + \varepsilon_x \tag{1}$$

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:

$$y = \lambda_y \eta + \varepsilon_y \tag{2}$$

with $\boldsymbol{y}$ being a vector of the measured indicator variables, $\boldsymbol{\lambda}_y$ the vector of (outer) loadings and ε_y 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 path 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 latent constructs and the latent endogenous constructs, or between two endogenous latent constructs can then be specified as follows:

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

With η representing the vector of endogenous latent 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 (Dijkstra 2010; Hair et al. 2017). Figure 3 entails an extract of our estimated model depicting the relations between inner and outer model, as well as the relations between indicators and latent constructs.

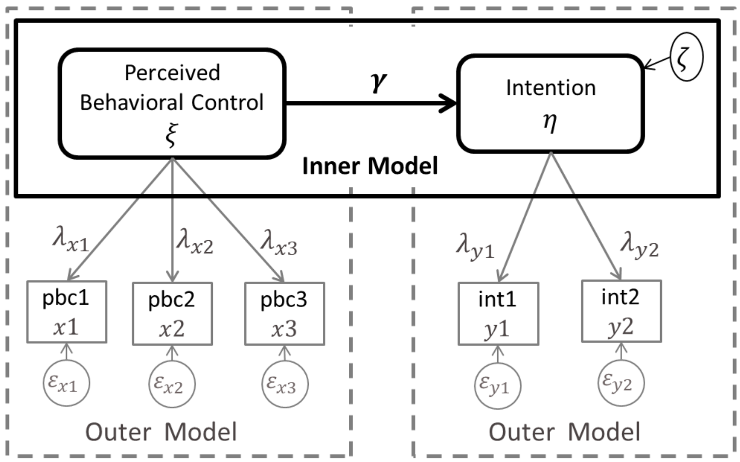

Figure 3: Illustration of PLS-SEM formal relations

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 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 the 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 5,000 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, which requires a continuous data structure. 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 an additional logit model based on maximum likelihood estimation for the adoption decision, assuming a logistic distribution of the error term ε. This model is suitable for binary responses. The latent factors scores for the intention to adopt mixed cropping ($\eta_{Intention_i}$) and the perceived behavioral control (ξ_{PBC_i}), which were established through the PLS-SEM, were included as the independent explanatory variables. Formally, the adoption decision is then specified as:

$$y = \begin{cases} 1 \; if \; Adoption > 0 \\ 0 \; if \; Adoption = 0 \end{cases} \tag{4}$$

$$Adoption_i = \beta_0 + \beta_1 \eta_{Intention_i} + \beta_2 \xi_{PBC_i} + \varepsilon_i \tag{5}$$

where i represents the individual respondent and ε_i is assumed to be a random error term. For an easier interpretation, the average marginal effects were calculated. To validate the model, 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 underscores the fact 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). The mean values for indicators referring to perceived ecological benefits are tending towards "partially agree/totally agree", implying that farmers are aware of the ecological benefits associated with mixed cropping.

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. This emphasizes the relevance of motivational factors for the intention to adopt mixed cropping. 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 (table 3). Consequently, hypothesis 1 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. Hypothesis 2, which stated that a higher perceived behavioral control increases the intention, is supported at the 1 % level of significance. Considering the descriptive results of the applied indicators, which all tended towards partial disagreement, 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 (hypothesis 4). In contrast, perceived social pressure from politics and society has a slightly negative effect on the intention to adopt, although not statistically significant (hypothesis 3). 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.

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)[a)]

Construct	**Statement**	**Mean (SD)**	**Outer loading**
Attitude towards Mixed Cropping (CR=0.881 AVE=0.651)			
atti1	I think that the cultivation of mixed stands offers many advantages	3.06 (0.97)	0.846***
atti2	The cultivation of mixed stands is important for sustainable production	3.13 (1.10)	0.847***
atti3	I think that economic importance of mixed cropping is going to increase in the future	3.39 (1.01)	0.819***
atti4	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)			
pbc1	I have the necessary knowledge to cultivate mixed stands	2.97 (1.14)	0.760***
pbc2	I have the technical capacity to cultivate mixed stands	2.92 (1.29)	0.735***
pbc3	I have the possibility to market the mixed yields	2.29 (1.17)	0.736***
Subjective Norm (CR=0.858 AVE=0.752)			
sn1	Sustainable production methods like mixed cropping are increasingly in the political focus and their adoption is expected	3.48 (1.04)	0.812***
sn2	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.)			
ign1	My farming friends, who are important to me, think that mixed stands are advantageous compared to pure stands	2.46 (1.06)	n.a.
Perceived Ecological Benefits (CR=0.861 AVE=0.673)			
peb1	Mixed cropping positively affects biological diversity	4.34 (0.83)	0.838***
peb2	Mixed stands can contribute to the preservation and improvement of soil quality	4.28 (0.82)	0.794***
peb3	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)			
int1	I intend to integrate mixed stands into my crop rotation	2.64 (1.25)	0.925***
int2	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)] reversely coded

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 research which explicitly included social identity theory into the TPB, applying group norm and subjective norm separately (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 differing 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 plausible considering the limited political attention, they support this line of reasoning. Furthermore, this indicates that farmers could show reactance, if there is an increase in legislative activity to increase mixed cropping adoption on a mandatory basis; reactance can be described as defiance against measures that limit one's behavior (Miron and Brehm 2006). If a mandatory scheme to facilitate adoption of mixed cropping were introduced, farmers would have to comply with the rules. However, in cases where an individual cannot return to the previous behavior, the attractiveness of the enforced behavior subjectively decreases (Miron and Brehm 2006). For mixed cropping, this implies that a mandatory scheme could deteriorate farmers' attitude, which in turn would hinder voluntary adoption. Therefore, voluntary agri-environmental schemes are preferable to facilitate adoption.

In addition, our results show that the descriptive group norm also has a statistically positive effect on the intention, as was postulated in hypothesis 5. 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 to 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. 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.

As was hypothesized, our additional construct "Perceived Ecological Benefits" has positive path coefficients towards the attitude and intention. The construct can explain 8.9% of the variance in the attitude

(R^2), indicating that the farmer's attitude is only partially formed by the ecological benefits. The effect on the intention is only very slightly positive and not statistically significant; hence hypothesis 6b cannot be supported. These results highlight that practice characteristics, in our case ecological benefits, can influence the intention of farmers to adopt mixed cropping, at least indirectly by influencing the attitude (hypothesis 6a). 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.

Table 3: Estimation results for proposed research framework (N=172)[a)]

PLS-SEM results for intention to adopt mixed cropping (R^2=52.40 %; Q^2=38.30%)				
Hypotheses		Path coefficients	t-statistic[a)]	Hypothesis supported?
H1	Attitude → Intention	0.479***	6.268	Yes
H2	Perceived Behavioral Control → Intention	0.227***	4.230	Yes
H3	Subjective Norm → Intention	-0.067	1.083	No
H4	Injunctive Group Norm→ Intention	0.155**	2.570	Yes
H5	Descriptive Group Norm → Intention	0.192***	3.255	Yes
H6a	Perceived Ecological Benefits → Attitude	0.298***	2.917	Yes
H6b	Perceived Ecological Benefits → Intention	0.042	0.534	No
Logit model results for adoption of mixed cropping (R^2=44.08%)				
Hypotheses		Marginal Effects	z-statistic	Hypothesis supported?
H7	Intention → Adoption	0.147***	5.89	Yes
H8	Perceived Behavioral Control → Adoption	0.032	1.52	No

a) Asterisks indicate different levels of significance (*** p<0.01, ** p<0.05, *p<0.10)
b) based on bootstrapping with 5,000 runs;

In order to assess factors influencing the actual adoption of mixed cropping we estimated a logit model including the latent variables "Intention" and "Perceived Behavioral Control" from the estimated structural model (Log-Likelihood: -37.839; Likelihood ratio chi² (2)=59.65 p=0.000). A classification test showed that the model correctly classifies 90.12% of the responses. To evaluate the goodness-of-fit of the model, the Hosmer-Lemeshow Chi-Squared test was performed. With a not statistically significant test statistic (chi²(8)=3.43 p=0.9046), the null hypothesis, that expected and observed outcomes are consistent, is supported. With a pseudo R^2 value of 44.08%, the model displays an excellent fit. These high values for the quality criteria of the model emphasize the relevance of psychological constructs in understanding farmers' behavior in the context of mixed cropping.

As was postulated by the TPB, we can support hypothesis 7 that the intention to adopt mixed cropping is a strong indicator for the actual adoption behavior. The effect for intention is significant at the 1% level. With an average marginal effect of 0.147, the 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 (hypothesis 8, 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 PBC 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. These differing results for perceived behavioral control on the adoption behavior indicate that it could be beneficial to include measures for actual behavioral control in future research.

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, leading to the ranking displayed in figure 3. According to our results, missing sales opportunities for mixed yields is the most crucial obstacle for the practical realization of mixed cropping. 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. As the technology in and around the agricultural sector has evolved around dominant mono stands, resulting in a technological “lock-in” (Meynard et al. 2018), 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 farmers in our sample.

The perception of insufficient economic benefits as one of the most crucial obstacles implies 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 to 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 to their corresponding pure stands (Bedoussac et al. 2015; Loïc et al. 2018; Pelzer et al.

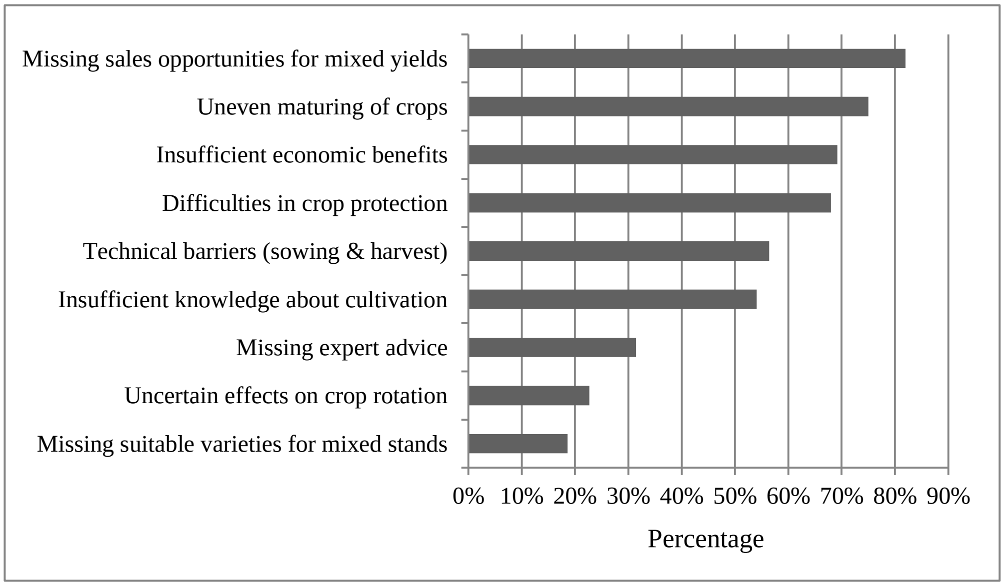

Figure 4: Responses (N=172) regarding obstacles perceived as most important for the practical implementation of mixed cropping. Respondents could choose up to five different obstacles, 95% chose the maximum number of obstacles.

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. 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, its ranking by famers among the most crucial obstacles to adoption indicates that knowledge regarding such practices should be better communicated to potential users.

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 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. We also show that social group norms positively influence farmer's intention to adopt mixed cropping. This 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.

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 overshadowed by many 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. Applying an extended version of the Theory of Planned Behavior has allowed us to identify attitude, perceived behavioral control, as well as 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 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. 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, confirming 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.

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. Our results also imply that an increase in legislative activity to expand the adoption on a mandatory basis might not be purposeful to enhance overall adoption and could cause reactance. 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. 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 adoption it is therefore necessary to 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, which can also be described as farmers' willingness to adopt, further research could include socio-economic variables, to evaluate farmers' ability to adopt (Mills et al. 2017). Focusing on the economic aspects, it might also be interesting to evaluate farmers' willingness to accept with respect to the profitability of mixed cropping.

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