FACTORS INFLUENCING THE ADOPTION OF HERBICIDE RESISTANCE TESTS IN GERMAN AGRICULTURE

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Summary

The ban on active ingredients in chemical crop protection and the resulting shortage of available tools in the future emphasize the importance of herbicide resistance management in arable farming. Resistance testing allows farmers to get an objective overview of the prevailing herbicide resistance on their land and to adjust their resistance management accordingly. Yet no study has investigated farmers' adoption of herbicide resistance tests. For this purpose, an only study with 200 German arable farmers was conducted in 2021. The adoption decision was investigated by applying the Theory of Planned Behavior framework. Estimation of the model was carried out using partial least squares structural equation modelling and a logistic regression. The results suggest that improving farmers' attitudes by communicating associated benefits of using herbicide resistance tests can facilitate its widespread adoption. Furthermore, awareness of the availability of herbicide resistance tests needs to be raised by advertising and crop consultants. Results from this study are of relevance for several groups of interest as they can help to promote herbicide resistance tests, ensure that the available range of active ingredients is not further restricted by emerging resistances, and in the long run help to ensure farm profitability and food safety.

Keywords

herbicide resistance; weed management; partial least squares structural equation modelling; theory of planned behavior; herbicide resistance management.

1 Introduction

Intensive farming practices in modern conventional agriculture systems are heavily dependent on the use of fertilizers and pesticides to protect and enhance yields (PRETTY, 2018; TILMAN et al., 2011). In fact, the application of pesticides has brought massive increases in food production (HICKS et al., 2018). According to ERVIN et al. (2019), weed-sensitivity to herbicides is an under-appreciated ecosystem service. By disrupting biochemical and/or physiological processes, herbicides kill weeds and thereby ensure a strong yield and quality of the crop. However, one of the consequences of incorrect herbicide use is the development of herbicide resistance. Herbicide resistance can be defined as "the inherited ability of a weed population to survive a herbicide application that is normally lethal to the vast majority of individuals of that species" (POWLES et al., 1996). The evolution of herbicide resistance is directly correlated to the frequency of historical herbicide use (HICKS et al., 2018), which is unavoidable if the weed management is based exclusively on one active ingredient (BAGAVATHIANNAN and DAVIS, 2018). Furthermore, the scarcity of new products and the ban of many active ingredients make resistance cases in the future even more likely (PETERSON et al., 2018). Herbicide resistance may force farmers to switch to different crops or non-chemical options, which can threaten farm profitability and ultimately farmers' economic well-being. Furthermore, the increased occurrence of herbicide resistance threatens food security and can cause further environmental and human health damage by overuse or the addition of further active ingredients to the mixture by the farmer (PANNELL et al., 2016).

ULBER and RISSEL (2018) showed that farmers have relied mostly on experts and their own perception in detecting herbicide resistance. However, herbicide resistance testing could be a valuable tool to gain cost-effective, objective knowledge about the emergence of herbicide resistance at an earlier stage. By using the results of an herbicide resistance test, which provides a detailed overview of resistance to active ingredients, farmers can adjust their weed control more easily and tailor it to the current situation. Furthermore, herbicide resistance tests can also ensure that the range of active ingredients is not further restricted for a farmer by promoting sustainable herbicide resistance management. Hence, the use of herbicide resistance tests can result in economic and ecological benefits. Lastly, with the help of this instrument, food security is also ensured. Despite the many advantages, the adoption of herbicide resistance tests is not yet widespread among farmers. Even more surprisingly, no study has yet looked at farmers' attitudes and decision-making with respect to herbicide resistance tests.

Farmers' adoption decisions are not usually solely based on objectively measurable benefits, otherwise all farmers would make the decision to adopt a technology or practice at the same time. It has been argued that ignoring the influence of social-psychological factors (e. g. attitudes and beliefs) in the adoption process could result in an incomplete understanding of farmers' behavior (e. g. AUSTIN et al., 1998). Likewise, in the case of herbicide resistance management practices, HURLEY and FRISVOLD (2016) stress that economic factors provide important incentives, but they are not the only motivators for farmers. Lastly, with respect to voluntary adoption decisions, focusing on the behavioral perspective is particularly warranted if it is the goal to motivate adoption (DESSART et al., 2019) as it is the case for herbicide resistance tests. Hence, it is reasonable to focus at first sight on social-psychological factors in this case.

A well-known theoretical framework, which accounts specifically for the influence of social-psychological factors in decision-making, is the theory of planned behavior (TPB) (AJZEN, 1991), which has also been previously used in the context of pesticide application in terms of integrated pest management practices (DESPOTOVIĆ et al., 2019; REZAEI et al., 2019) or the use of pesticides (BAGHERI et al., 2019). The TPB aims to explain and predict an individual's behavior. More specifically, the theory focuses on the self-controlled, goal-directed and voluntary behavior. According to theory, individuals' attitude, social norm as well as perceived behavioral control influence the intention and ultimately the specific behavior in question (AJZEN, 1991). As said before, no attention has been paid to understanding farmers' behavior with respect to the adoption of herbicide resistance tests. In addition, the compatibility of the TPB framework to explain farmers' behavior in this context has not yet been examined.

To fill these research gaps, this study aims to understand farmers' attitude and behavior towards the use of herbicide resistance tests by using the TPB framework. To the best of our knowledge, this is the first study to examine the influence of attitudinal variables on farmers' adoption process of herbicide resistance tests. For this purpose, an online study was conducted in the first quarter of 2021 with 200 German conventional arable farmers. The model for the adapted TPB was estimated using partial least squares structural equation modelling (PLS-SEM) (HAIR et al., 2022) and a binary logit model. Results from this study are of interest for researchers, farmers as well as extension services and providers of herbicide resistance tests as they have both theoretical and practical implications. Understanding farmers' attitudes and behavior towards the use of herbicide resistance tests can facilitate the adoption of these instruments in conventional arable farming and ultimately the adoption of herbicide resistance management strategies. In this vein, extension services can use the results to increase awareness and adoption rates of herbicide resistance tests among the farmers. Likewise, providers of herbicide tests can improve their marketing activities based on the results. In consequence, the study can help to ensure that the available range of active ingredients is not further restricted by emerging resistances. In the long run, the promotion of herbicide resistance testing by using the results of this study can help to ensure farm profitability and food safety. At a larger level, this study provides an empirically verified theoretical framework for researchers to investigate farmers' behavior regarding the use of herbicide resistance tests in other country settings.

2 Hypotheses Generation

In the TPB, an individual's intention predicts his or her behavior. The intention originates from the latent constructs attitude, social norm and perceived behavioral control (AJZEN, 1991). The latent construct attitude in the TPB measures an individual's positive or negative evaluation of the behavior in question (AJZEN, 1991). With respect to herbicide resistance tests, the latent construct represents farmers' evaluation of the usefulness of and interest in the tests results, respectively. A more positive general attitude towards herbicide resistance tests generally increases farmers' intention while a negative general attitude decreases it as displayed in the following hypothesis:

H1: General attitude influences farmers' intention to use herbicide resistance tests

Social norm is the latent construct in the TPB which refers to an individual's perceived social pressure to comply with (or not) the behavior in question. More specifically, social norms represent the influence of an individual's social environment (e. g. colleagues, extension services) on his decision-making process (AJZEN, 1991). With regard to pesticide application, the opinions of professional colleagues and advisors play a major role for farmers (PANNELL and ZILBERMAN, 2001). Accordingly, it can be assumed that the opinion of professional colleagues and advisors also have an influence on the intention to use herbicide resistance tests as shown in the following hypothesis:

H2: Social norm influences farmers' intention to use herbicide resistance tests

Perceived behavior control refers to the extent an individual perceives performing the behavior in question to be difficult or easy (AJZEN, 1991). More specifically, perceived behavioral control can be attributed to an individual's engagement in the behavior in question based on their access and requirement of resources (e. g. money, time, skills) (AJZEN, 1985). In terms of herbicide resistance testing, this means access to herbicide test providers, the time commitment of collecting and sending in the seeds as well as correctly interpreting the resistance profile and transferring its implications to the on-farm weed management. When the person perceives the execution of the behavior as easy (difficult), the intention to perform the behavior increases (decreases). The following hypothesis is therefore derived:

H3: Perceived behavioral control influences farmers' intention to use herbicide resistance tests

Weeds cause average yield losses of 35 % worldwide (HICKS et al., 2018). The costs incurred by farmers due to weeds are composed of yield and quality losses (ALEMSEGED et al., 2001; NORSWORTHY et al., 2012). Loss of control through herbicide resistances can double economic costs of weeds (Hicks et al., 2018). However, LIVINGSTON et al. (2016) noted that adjustments to the weed management due to resistances may reduce profits in the first years, but can increase profits in the long run. Hence, if a farmer perceives that he or she can (not) use active substances more efficiently on the basis of resistance test results and that the profits (do not) exceed the costs in the long term, he or she will have a higher (lower) intention to use herbicide resistance tests and a more positive (negative) general attitude towards the tests.

H4a: Perceived economic benefits influence farmers' general attitude towards herbicide resistance tests

H4b: Perceived economic benefits influence farmers' intention to use herbicide resistance tests

PANNELL and ZILBERMAN (2001) emphasize that farmers may apply pesticides sub-optimally, which, due to its lack of efficiency, can lead to overuse, which in turn can result in a greater environmental impact. Furthermore, farmers often respond to resistant weeds with herbicide mixtures with additional active ingredients having more environmental effects and also increasing the possibility of building new resistances (PANNELL et al., 2016). However, farmers who are highly concerned about negative externalities in using pesticides are more likely to take measures to reduce pesticide use (BAKKER et al., 2021; STALLMAN and JAMES, 2015). Reliable results of herbicide resistance tests can serve as a motivator to use the optimal amount of active ingredients or to adjust weed management efficiently, which can be an alleviation for the environment through less overuse of herbicides. Hence, if a farmer perceives that he or she can (not) use active substances more efficiently for the benefit of the environment on the basis of resistance test results, he or she will have a higher (lower) intention to use these instruments and a more positive (negative) general attitude towards the tests. The following hypotheses are therefore derived:

H5a: Perceived ecological benefits influence farmers' general attitude towards herbicide resistance tests

H5b: Perceived ecological benefits influence farmers' intention to use herbicide resistance tests

In the TPB framework, the latent constructs *Perceived Behavioral Control* and *Intention* influence directly the actual behavior in question. The lower the probability that the behavior in question is actually performed, the lower the intention of the individual is, regardless of whether the individual is able to do so (AJZEN, 1991), which can be assumed to also hold true for the usage of herbicide resistance tests. Furthermore, a higher perceived behavioral control also increases the likelihood of the actual performance of the behavior in question (AJZEN, 1991). Therefore, it can be assumed that the latent construct *Perceived Behavioral Control* also plays a critical role for the adoption. The following hypotheses reflect these considerations:

H6: Perceived behavioral control influences farmers' actual adoption of herbicide resistances tests

H7: Farmers' intention to us herbicide resistance tests influence farmers' actual adoption of herbicide resistances tests

3 Material and Methods

An online survey addressed to German farmers was conducted in the first quarter of 2021. Farmers were invited to participate in the survey via agricultural newsletters and social media. The farmers were asked once via the named channels to take part; no subsequent invitation was sent out. The survey was divided in three parts. In the first part, farmers were asked to provide socio-demographic and farm related information. In the second part, surrounding information about on-farm herbicide resistance was asked for. Furthermore, farmers were asked if they have used a herbicide resistance test (yes/no). In the third part, farmers were asked to indicate their approval to 19 randomized indicator statements on a 5-point Likert scale (1 = high disagreement; 5 = high agreement). The statements are used to estimate the latent constructs in the model as proposed in section 2. Before the evaluation of the statements, the farmers received an explanatory text to herbicide resistance tests to ensure that all farmers have a basic knowledge of resistance testing in order to be able to evaluate the statements in a reliable way. To further ensure the quality of the answers, the farmers were explicitly asked to click on a specific answer on the Likert scale at one point in the survey. If they clicked incorrectly at this point, they were asked politely to read the statements carefully and then had to evaluate the statements again. If farmers still answered the quality check question wrong, they were excluded from the survey immediately. To address the research question in a meaningful way, we purposively sampled conventional arable farmers who manage at least five hectares of arable land (GERMAN FARMERS' ASSOCIATION, 2021). Furthermore, we ensured that all farmers have winter cereals in their crop rotation as these are the dominating crop rotations in Europe (PETERSON et al., 2018). These farmers are objectively most likely the ones who are dealing with weed management issues and possible herbicide resistances. Finally, the sampling method ensured transferability of the results to other regions in Europe with comparable cropping systems.

Estimations were carried out using partial least squares structural equation modelling (PLS-SEM) up to the intention to use herbicide resistance tests. With respect to PLS-SEM, the evaluation is carried out in two steps: First, the outer model is estimated. The measurement model assessment includes indicator reliability (loadings λ), internal consistency (composite reliability, CR), convergent validity (average variance extracted, AVE) and discriminant validity (Heterotrait-Monotrait ratios ($HTMT$)) (HAIR et al., 2022; HENSELER et al., 2015). Indicator reliability is established if standardized loadings exceed the threshold of 0.7, which indicates that more than 50 % of the indicator's variance is explained by the latent construct. Values for composite reliability $CR > 0.7$ and < 0.95 establish internal consistency which means that all indicators to be tested measure the same latent construct. Convergent validity is established by estimating the average variance extracted $AVE,$ which should exceed the threshold of 0.5. An AVE value above 0.5 indicates that a latent construct explains more than half of the variance of its indicators. Values for the $HTMT$ correlations should not exceed 0.9 to establish discriminant validity. Discriminant validity ensures that all latent constructs are separable from each other and that indicators only represent one latent construct (HAIR et al., 2022). Before estimating the structural model, variance inflation factors (VIF) are estimated to check for multicollinearity. Second, in the structural model, the relationship between exogenous and endogenous latent constructs is estimated and given as standardized path coefficients β (direct effect). A bootstrapping procedure with 10,000 subsamples is applied to estimate t-statistics to check for statistical significance of the standardized path coefficients (β) and also to estimate confidence intervals for the $HTMT$ values. Furthermore, explained variance (R^2) and out of sample-predictive relevance (Q^2) are estimated. Q^2 values are estimated using a blindfolding procedure with an omission distance of seven. Estimation of the PLS-SEM was carried out using *SmartPLS* 3.2.7 (RINGLE et al., 2015).

The target endogenous variable in the model is a binary variable with the following specification: 1 = adoption of herbicide resistance tests and 0 = no adoption of herbicide resistance tests. Applying the estimation procedure of PLS-SEM to the binary variable in the model would result in biased standard errors (HAIR et al., 2012). Hence, the latent factor scores for the intention and perceived behavioral control were implemented in a logistic regression for the binary adoption variable.

4 Results and Discussion

4.1 Descriptive Results

200 fully-answered questionnaires were used for the analysis. With respect to socio-demographic and farm characteristics, the sample is slightly biased towards younger farmers than the German average. The average farmer is 45 years old (German average is 53 years old). With respect to farm size, farms with a size between 50 and 500 hectares of arable land are slightly overrepresented, while farms with more than 500 hectares are slightly underrepresented. With respect to farms smaller than 50 hectares of arable land, the sample is close to the German average. The average farm size in the sample is 335 hectares of arable land. The sample contains a higher share of male farmers (96.5 %) than the German average (90 %). Furthermore, 46.5 % of the farmers in the sample hold a university degree which far exceeds the German average of 12 %. With respect to the farm locations in Germany, more than half of the farmers in the sample are from the northern region (51.5 %) which exceed the German average, while the southern region is underrepresented (16 %). The share of farmers living in the eastern or western regions (5%; 27.5 %) is close to the German average (7%; 24%)

(GERMAN FARMERS' ASSOCIATION, 2021). The share of winter cereals in the average farmer's crop rotation amounts to 51.8 %. As expected due to our sampling method, 97 % of the farms are managed purely as conventional. Only, 3 % of the farms have an additional organic branch on their farm. Lastly, the average farmer in the sample is risk neutral as shown by the mean score of 5.5 on the 11-point scale based on DOHMEN et al. (2011). In the sample, 16.5 % of the farmer have used a herbicide resistance test. Only 22 % are sure that they have no herbicide resistant weeds on their farm, while 55.5% are certain to have at least one herbicide resistant weed. 22.5 % of the respondents are not sure. From the farmers who are sure they have herbicide resistant weeds or are unsure if they may have herbicide resistant weeds on the farm, 84.6 % have already adjusted their weed management. Furthermore, more than 70 % of the farmers wish for more information about herbicide resistances. Lastly, more than 80 % of the farmers agree that new resistance-free herbicides will be registered in Germany in the future.

To conclude, the sample is slightly biased in terms of socio-demographic and farm characteristics. However, as all farmers in the sample are conventional arable farmers with winter cereals in their crop rotation, the sample can be described as valid for the research purpose regarding the use of herbicide resistance tests.

4.2 Estimation Results

The indicator loadings are, with four exceptions (min. 0.612), above the common rule of thumb of 0.7 (HAIR et al., 2011). However, as pointed out by CHIN (1998), only indicators with loadings less than 0.5 should be dropped. Furthermore, HAIR et al. (2022) recommend that indicators below the threshold 0.7 should be retained in the model due to their impact on further model results and content validity. Lastly, a bootstrapping was applied to assess the statistical significance of each indicator loading. Since all indicator loadings are statistically significant ($p < 0.001$) and due to the recommendation in the literature, all indicators are retained in the model as proposed. All values for CR and AVE exceed the recommended threshold of 0.7 and 0.5, respectively. Hence, the results for each latent construct's CR establish internal consistency. Likewise, estimated constructs' AVE provide the necessary evidence for convergent validity in the model. Furthermore, variance inflation factors were estimated (VIFs, max. 2.575; min. 1.136). VIFs < 5 indicate that multicollinearity is not at a critical level (HAIR et al., 2022).

While not all indicator outcomes can be examined in detail, some results are remarkable: The latent construct *General Attitude* showed the highest overall mean, which indicates a clear positive attitude towards the use of herbicide resistance tests among the farmers (mean = 4.263). Likewise, the overall mean for the latent constructs *Perceived Economic Benefits* (mean = 4.140) and *Perceived Ecological Benefits* (mean = 3.870) indicate a relatively high level of agreement that the use of herbicide resistance tests is associated with economic and ecological benefits. Looking at the highest agreement among the indicators for the latent construct *Perceived Economic Benefits* shows that the statement "Herbicide resistance testing allows me to use active ingredients more efficiently" had the highest mean value (mean = 4.250). For the latent construct *Perceived Ecological Benefit*, the statement "The use of herbicide resistance testing is important for sustainable management in arable farming" achieved the highest level of agreement (mean = 3.980). Another noteworthy result is the overall mean value for the latent construct *Perceived Behavioral Control,* which is the lowest for all latent constructs (mean = 3.213). Equally noteworthy is the gap in the mean agreement values for the indicators of the named latent construct. While the statement "I have the knowledge necessary to transfer herbicide resistance test results into my weed management" showed a mean value of 3.890, the statement "I have access to herbicide resistance testing providers" only achieved a mean value of 2.660. The results reveal that farmer feel they are able to integrate results of the herbicide resistance tests in their weed management. Nonetheless, a perceived lack of access to providers is clearly stated by farmers.

Discriminant validity is supported since no $HTMT$ ratio exceeds the threshold of 0.9 (max. 0.887) (HAIR et al., 2022; HENSELER et al., 2015). In this case, we used the less conservative threshold of 0.9 for the $HTMT$ ratio, since we included three conceptually related latent constructs in the model (*General Attitude, Perceived Economic Benefits, Perceived Ecological Benefits*). However, to no only rely on the threshold, we also estimated the 95% percentile confidence intervals (CI_{95}) of the $HTMT$ ratios. According to HENSELER et al. (2015), a lack of discriminant validity can be excluded if a value of 1 does not fall in the CI_{95}, which holds true for our results (max. CI_{95} = 0.971)

Table 1 shows the model results. Explained variance (R^2) of the latent constructs *General Attitude* and *Intention* in the structural model amount to 0.555 and 0.478, respectively. The results indicate that 48 % of the variation in the farmers' intention is explained by the latent constructs *General Attitude, Social Norm, Perceived Behavioral Control, Perceived Economic Benefits* and *Perceived Ecological Benefits*. Also, 56 % of the variation in farmers' general attitude is explained by the latent constructs *Perceived Economic Benefits* and *Perceived Ecological Benefits*. Furthermore, values for Q^2, which were estimated with an omission distance of seven, are larger than 0 which indicates a sufficient predictive relevance of the model (HAIR et al., 2022). The results of the structural model indicate that the proposed extended TPB model is able to capture a large amount of latent information in the adoption process of herbicide resistance tests.

Farmers' general attitude has a statistically significant influence on the intention to use herbicide resistance tests (β = 0.435***), so the first hypothesis (H1) is given support. Hence, higher levels of a positive general attitude towards herbicide resistance tests lead to a higher intention to use this instrument. Results also show that perceived behavioral control has a statistically significant positive relationship with the intention to use herbicide resistance tests (β = 0.204***). Thus, the second hypothesis (H2) is given support by the model. This means that if a farmer perceives difficulties performing a herbicide resistance test, the intention to perform a test decreases. The results also support the third hypothesis (H3) which proposes a statistically significant effect of social norms on farmers' intention to use herbicide resistance tests (β = 0.182**). Thus, perceived pressure from other farmers and crop consultants reinforces farmers' intention to use such tests. Hypotheses 4a und 4b deal with the effect of perceived economic benefits on the general attitude (H4a) and intention to use herbicide resistance tests (H4b). The path coefficient of perceived economic benefits is statistically significant for the general attitude towards herbicide resistance tests in a positive direction (β = 0.514***). However, no statistically significant effect could be found for the path coefficient of perceived economic benefits on the intention to use herbicide resistance tests. Hence, H4a can be given support, while H4b can be given no support by the model. This means that a higher level of perceived economic benefits in using herbicide resistance tests improves general attitude towards the tests, but has no effect on the intention to use them. Comparable implications emerge for the results of hypotheses 5a and 5b. While perceived ecological benefits statistically significantly influence farmers' general attitude towards herbicide resistance tests (H5a) in a positive direction (β = 0.296***), no statistically significant effect was found for the path coefficient linking perceived ecological benefits and farmers' intention to use herbicide resistance tests (H5b).

To investigate possible indirect effects, we conducted a mediation analysis. By means of the mediation analysis, we test for the statistically significant indirect effects of perceived economic and ecological benefits via the general attitude towards the intention to use herbicide resistance tests. The indirect effects can be seen as the sequence of the two direct effects. Hence, the indirect effect of perceived economic benefits via the general attitude on the intention is the product of the successive path coefficients (0.224 = 0.514 × 0.435), which is statistically significant with $p < 0.001$. Likewise, the indirect effect of perceived ecological benefits via the general attitude on the intention (0.129 = 0.296 × 0.435) is statistically significant at $p = 0.001$.

Since the direct effects are not statistically significant (results for H4b and H5b) and the indirect effects are statistically significant, the results imply that the general attitude fully mediates the perceived economic and ecological benefits to the intention to use herbicide resistance tests (HAIR et al., 2022) . Hence, higher levels of perceived economic and ecological benefits lead to a positive increase in the general attitude, which in turn leads to a higher intention to use herbicide resistance tests.

Table 1: Structural model and logistic regression results (N = 200)

Partial Least Squares Structural Equation Modelling [a]				
Path		**β**	**t**	**Support H?**
General Attitude → Intention	H1	0.435***	5.443	Yes
Perceived Behavioral Control → Intention	H2	0.204***	3.873	Yes
Social Norm → Intention	H3	0.182**	2.837	Yes
Perceived Economic Benefits → General Attitude	H4a	0.514***	6.753	Yes
Perceived Economic Benefits → Intention	H4b	0.124 n. s.	1.408	No
Perceived Ecological Benefits → General Attitude	H5a	0.296***	4.138	Yes
Perceived Ecological Benefits → Intention	H5b	-0.047 n. s.	0.558	No
Logistic Regression [b]				
Path		**OR** [c]	**z**	**Support H?**
Perceived Behavioral Control → Adoption	H6	5.238***	3.62	Yes
Intention → Adoption	H7	4.343***	4.98	Yes

[a] General Attitude (R^2 = 0.555; Adjusted R^2 = 0.550; Q^2 = 0.363), Intention (R^2 = 0.478; Adjusted R^2 = 0.464; Q^2 = 0.376)

[b] log likelihood = -49.447, LR chi^2 (2) = 80.25***, McFadden Pseudo R^2 = 0.448, McKelvey & Zavoina Pseudo R^2 = 0.673, Nagelkerke Pseudo R^2 = 0.559, Link test n. s., Hosmer-Lemeshow chi^2 (8) = 2.46 n. s., Pearson chi^2 (164) = 106.09 n. s., Correctly classified = 91 %

[c] Odds ratio > 1 indicate a positive effect; Odds ratio < 1 indicate a negative effect

***p < 0.001, **p < 0.01, *p < 0.05, n. s. = not statistically significant; H = Hypothesis; OR = Odds ratio

Table 2 shows the mean index values of the inner models' latent constructs and the total effects (indirect + direct effect) of the latent exogenous constructs on the latent endogenous constructs. The latent constructs' values are rescaled so that they can take values between 0 and 100. The mean index values indicate the constructs' performance (0 = lowest performance, 100 = highest performance). The total effect expresses the exogenous latent constructs' importance in predicting the target latent endogenous construct. In addition, Figure 1 shows the results of Table 2 graphically in an importance-performance map (IPMA) (RINGLE and SARSTED, 2016) based on the estimated structural model up to the latent construct *Intention*. IPMA results allow to identify areas of improvement which can be addressed by management and marketing activities. In order to increase the endogenous latent constructs' performance, one should focus on latent constructs with relatively high importance (i. e. high total effect; x-axis) and relatively low performance (y-axis) (HOCK et al., 2010; RINGLE and SARSTED, 2016).

The results in Table 2 and Figure 1 imply that the latent constructs *General Attitude* and *Perceived Economic Benefits* are highly relevant for increasing farmers' intention to use herbicide resistance tests due to their relatively high total effects. However, as both latent constructs have a high performance level, there is minor potential for a further increase. Hence, efforts should be taken in maintaining these performance levels or, if possible, expanding them. The latent construct *Perceived Ecological Benefits* is at first sight of less importance to increase farmers' intention as the total effect is relatively low. Furthermore, the performance of the latent construct is relatively high. Hence, *Perceived Ecological Benefits* have a relatively low impact on the intention and provide only minor potential for further improvement. However, *Social Norm* and *Perceived Behavioral Control* have reasonable total effects on the target latent construct and also offer more improvement potential in terms of performance.

Table 2: Index values and total effects

Latent construct	Index value	Total effect on *Intention* [a]
General Attitude	81.561	0.435
Perceived Behavioral Control	52.615	0.204
Social Norm	58.226	0.182
Perceived Ecological Benefit	72.523	0.082
Perceived Economic Benefit	78.581	0.347

[a] If no indirect effect is present, then the total effect is equal to the path coefficient (β) (Table 1).

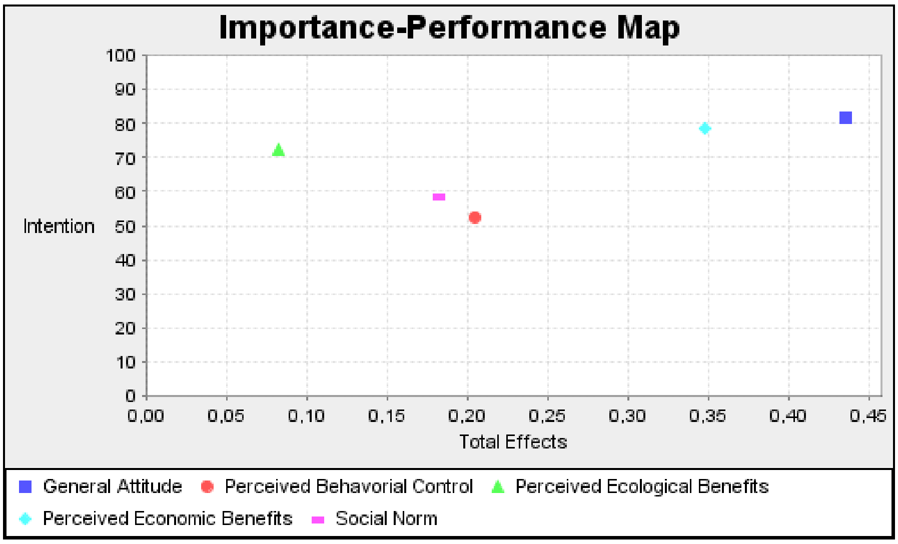

Figure 1: Importance-Performance Map for the target latent construct *Intention*

Lastly, the relationship between farmers' actual adoption decisions and the latent constructs *Intention* and *Perceived Behavioral Control* (H6, H7) is investigated via a logistic regression. The goodness-of-fit characteristics for the logit model are reported below Table 1. Results of the logistic regression show that the actual adoption of herbicide resistance tests is statistically significantly influenced by farmers' intention (OR = 4.343***) and the perceived behavioral control (OR = 5.238***). Hence, H6 and H7 are supported by the model. The logit model formally completes the analysis of the TPB and indicates that an intention-behavior gap is not present. In conclusion, the adoption of herbicide resistance tests can be predicted by using the TPB framework.

5 Scientific and practical implications

From the results of the structural model, it can be concluded that the general attitude is the most reliable predictor of farmers' intention to use herbicide resistance tests. A strong positive correlation between intention and general attitude suggest one strategy could be to communicate and emphasize that herbicide resistance tests are favorable for farmers. Herein, the results for the latent construct *Perceived Economic Benefits* in the IPMA (Figure 1) become relevant. Firstly, the effect of perceived economic benefits is fully mediated through farmers' general attitude towards the intention to use herbicide resistance tests. Secondly, farmers' general attitude and perceived economic benefits have the greatest impact on farmers' intention to use herbicide resistance tests. It is according to NORSWORTHY et al. (2012), scientifically clear that herbicide resistance management comes with short-term costs for farmers but includes long-term economic benefits by avoiding additional future costs due to resistances. However, farmers are most likely to focus on immediate economic costs with respect to herbicide resistance management (NORSWORTHY et al., 2012). Costs of herbicide resistance management are immediate as the farmer has to adjust his or her weed management. In contrast, benefits of an effective herbicide resistance management emerge at a later point in time, which encourage farmers to delay the adoption of herbicide resistance management strategies (HURLEY and FRISVOLD, 2016). Furthermore, it is also straight-forward for a farmer to calculate the costs of adding an additional active ingredient to the mixture, however calculating the long-term costs of resistance and benefits of herbicide resistance management come with great uncertainty (HURLEY and FRISVOLD, 2016). Hence, it should be the goal to persuade farmers to adopt herbicide resistance tests and possible subsequent measures by communicating that anti-resistance strategies costs are small compared to long-term costs of resistances. Herbicide resistance testing can serve as a robust, objective basis for convincing farmers to implement herbicide resistance management strategies. In this context, the long-term economic benefits of management adaptations need to be communicated.

Model results suggest perceived behavioral control serves as a predictor for farmers' intention to use herbicide resistance tests. Furthermore, the latent constructs with lowest performance in the IPMA (Figure 1) suggest major potential for improvement. Logically, increasing farmers' perceived behavioral control also increases their motivation and self-confidence in adapting new practices or technologies. Effective marketing campaigns and instructive efforts by crop consultants that educate farmers about herbicide resistance tests can reduce their uncertainty (PANNELL and ZILBERMAN, 2001). In this context, it is particularly important to ensure that farmers are aware of the availability of herbicide resistance testing.

As expected, social norm also serve as a predictor of farmers' intention to use herbicide resistance tests. Furthermore, the results of the IPMA map (Figure 1) suggest the latent constructs offer potential for performance improvement. This result is supported by the literature as the most important referents for farmers are neighboring farmers or experts (PERRY and DAVENPORT, 2020). The positive relationship between social norms and farmers' intention to use herbicide resistance tests suggest that other farmers can function as a channel to disseminate information about herbicide resistance tests and also persuade other farmers to adopt these instruments. In this vein, focusing on professional meetings of farmers where growers have the opportunity to interact directly with each other can be used to communicate the associated benefits in herbicide resistance testing. Furthermore, having neighboring farmers at these meetings has the advantage of counteracting farmers' feelings that they can't make any difference since neighboring farmers' decisions mean they will have the resistance problem anyway (SHAW, 2016). On the other hand, emphasizing the identified drivers of attitude through recommendations from crop consultants could also increase the intention of farmers to use herbicide resistance tests since they are an important source of information about the use of crop protection products for most farmers.

6 Conclusions

To sum it up, the present study has explored the influence of latent constructs on farmers' adoption behavior regarding the use of herbicide resistance tests. To this end, a model for an extended TPB was estimated using PLS-SEM and a binary logit model based on a sample of 200 German conventional arable farmers, collected in 2021. A similar approach with an associated study addressing farmers' adoption of herbicide resistance testing has not been reported in the literature so far. Hence, this study provides first and novel evidence for better understanding of farmers' behavior regarding the use of herbicide resistance tests that could be fruitful for researchers and farmers, as well as extension services and providers of herbicide resistance tests. While we strongly believe that our results are transferable to other European countries with comparable cropping systems and use of pesticides, future studies should still validate our results in other country settings for which this study provides the necessary framework. This holds especially true for the United States and Australia who have a comparable or more pronounced resistance problem, but different authorized herbicides and other usages (Pannell *et al.*, 2016).

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