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Potential of Eco-Weeding with High-Power Laser Adoption from the Farmers' Perspective

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Abstract: Agriculture and rural regions in Europe face a number of economic, social, and environmental challenges. Rural areas are active players in the EU's green transition. Weeding is one of the most important factors in agricultural production. New weeding techniques are being developed to enhance sustainability. Among them, laser-based weeding seems to be a promising alternative to the use of chemicals. The WeLASER technique is a novel technique for weed control. Its successful implementation depends on many factors related to the innovation itself, policy context, farming conditions, and users' attitudes. A survey was carried out to provide insight into the attitudes towards the innovative (laser) weed control tool (autonomous robot). The CATI method was selected for the surveying of farmers' opinions and carried out in three countries: Denmark, Spain, and Poland. Statistical methods were applied to analyze the results. This study provided knowledge on how farmers see the barriers and opportunities related to implementing the device in practice. Positive attitudes of farmers were observed but with high expectations related to the quality of the technique and the systemic conditions of its implementation.

Keywords: laser; weeding technique; autonomous robot; sustainable agriculture; CATI survey; farmers' perspective; crosstabs; Pearson's chi-square statistic; Cramer's V coefficient; column proportions

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1. Introduction

Agriculture and rural regions in Europe face a number of economic, social, and environmental challenges [1,2]. Rural areas are active players in the EU's green transitions. Through the sustainable production of food, preservation of biodiversity, and the fight against climate change, they play a key role in achieving the European Union's Green Deal [3], Farm to Fork [1], and biodiversity targets [4], as well as the goals of the long-term vision for the EU's rural areas [5]

The sustainability of the agricultural sector depends in many ways on its further innovation. Innovation covers many aspects: technical, social, and economic. One of the crucial developments lies in digitalization as well as robotization [6,7]. Digital technologies are the key to a smarter, more competitive, and resource-efficient agricultural sector [8]. EU farmers already benefit from digital solutions that can help their farms to become more sustainable. Moreover, digitalization increases economic, social, environmental, and geopolitical resilience. Machines enable the digital transformation of agriculture by using sensors on machines to detect actual soil and crop information (weed recognition, amount of biomass, nutrient status, pests, and diseases), which allows for mapping to ensure the successful control of variable rate applications, communication protocols, and cloud connectivity to facilitate data flow [2,9–15]. There is an increasing role that knowledge and information can play in gaining control of resources, increasing profits, and reducing risk in farming [16,17].

There are many benefits of precision agriculture (PA) for farmers. It improves the productivity and profitability of the farm and automation of machine operations, improves comfort, lowers the CO_2 footprint and water contamination with nitrate and pesticides, and improves the public image of farming. The use of Hi-Tech can attract young people to farming and keep them in rural areas [2,18].

Precision agriculture helps farmers to adjust to policy requirements concerning environmental protection. The use of herbicides on organic farms is banned in Europe [19–22], stimulating changes in crop production systems. In addition, consumer habits are forming, and there is growing concern about access to safe food.

Adopting sustainable agriculture techniques boosts productivity and production, assists ecosystem sustainability, and strengthens the capacity to respond to climate change, extreme weather, droughts, floods, and other disasters, as well as progressively increasing land and soil quality [23]. It is also expected that problematic weed management (due to herbicide resistance, the lower efficacy of chemicals due to the timing of application, and weather-indicated lower efficacy) is acting as a driver for the adoption of non-chemical solutions [24,25].

Weeding is one of the most important factors in agricultural production. Weeds can lower the productivity in crop systems. Farmers are facing severe problems with weed competition [26]. New weeding techniques are being developed to meet the challenges of sustainable production. Automatic weed removal technology provides a path to alternative weed control tools that is much more promising, at least for specialty crops, than the traditional model, which is based on herbicide development [27]. These tools include laser-based weeding. Laser-based weeding seems to be a promising alternative to the use of chemicals. The WeLASER technique is a novel technique of weed control developed under the HORIZON 2020 project WeLASER, the objective of which is to reduce the use of herbicides while improving productivity and competitiveness. The WeLASER weeder is an autonomous mobile robot using a high-power laser to eliminate weeds. It is a complex solution using autonomous systems, artificial intelligence (AI), and advanced geo-positioning. The invention was developed, integrated, and tested in the "Sustainable Weed Management In Agriculture With Laser-based Autonomous Tools-WeLASER" project.

It comprises a mobile autonomous platform, a laser weeding unit, and supportive components. In the WeLASER project, a weeding system with two lasers was tested to achieve Technology Readiness Level 7 (TRL 7). To be commercialized, the product must attain further development by obtaining Technology Readiness Level 9 (TRL 9) status. The commercialization product will be equipped with four high-power lasers. The WeLASER machine has four baseline components: 1. an autonomous mobile platform; 2. a weed meristem perception system; 3. a smart central controller; 4. a laser-based weeding tool with a high-power laser source and a meristem targeting system.

The successful implementation of the technique depends on many factors related to the innovation itself, the policy context, the types of farming systems, conditions, and users' attitudes. Understanding the conditions of adoption of the technique is crucial both for its final design and commercialization and for developing business models for its application. Farmers' attitudes towards field crop robots in a European setting have hardly been studied, despite the increasing availability of the technology [28]. In social-science reviews, the singularity of agricultural robots is rarely considered [29]. It is instead resituated within the context of the diversity of digital innovations [30].

Knowledge of farmers' perceptions of technological innovations is important for agricultural machinery stakeholders, for research centers, and for policymakers [31].

In the study, the attitudes of the farmers towards innovation in agriculture in general terms and towards the WeLASER technique specifically were studied. A CATI survey was carried out for this purpose. In the study, the inter-relations between various factors determining the adoption of the new techniques were analyzed. The results of the study were intended to help improve the design and business models for its implementation and prepare recommendations for European policies regarding precision agriculture and the weed control system.

2. Materials and Methods

The overall aim of the survey is to gain insight into attitudes towards the innovative weed control tool (laser-based autonomous robot) and to obtain knowledge on whether farmers see an opportunity or not to implement it and what the barriers and possibilities of implementing the device in their practice are. The intention of the work was to obtain valuable insights into the future implementation of precision agricultural techniques in weed control. The research questions of the study are as follows:

- What experiences and attitudes do farmers have towards innovative farming tools based on automation, advanced electronics, communication, and artificial intelligence?
- What obstacles and opportunities could arise in the practical application of laser-based weed control tools such as WeLASER in practice?
- How would farmers' current experiences and expectations regarding the adoption of innovative technologies influence their attitudes towards WeLASER implementation?

According to the Diffusion of Innovation (DOI) theory presented by E.M. Rogers [32,33], adoption means that a person does something different from what they had done previously (i.e., purchase or use a new product/technology). The key to adoption is that the person must perceive the idea, behavior, or product as new or innovative.

Attitude towards technology is a key factor influencing the adoption of a wide range of technologies. An attitude is a psychological tendency expressed by evaluating a particular object with a certain degree of favor or disfavor. Consumers' attitudes towards technology affect the way they purchase, what they buy, when they purchase, and even how they pay for purchases. "Attitudes" are an integral part of the Theory of Reasoned Action (TRA); its modification, the Technology Acceptance Model (TAM); and the Theory of Planned Behavior. These theories/model include "attitudes" at their core.

Attitudes are understood as predictions of intentions and presuppose a rational ('reasoned', or 'planned') process [34–37]. An attitude can be defined as an evaluative judgment, either favorable or unfavorable, that an individual possesses and directs towards a specific object of attitude. In the context of technology, attitude towards technology is one's positive or negative evaluation of the introduction of new kinds of technologies in a particular environment [32,33,38]. The conceptual framework is presented in Table 1.

The concept of assessment is presented in the figure below (Figure 1).

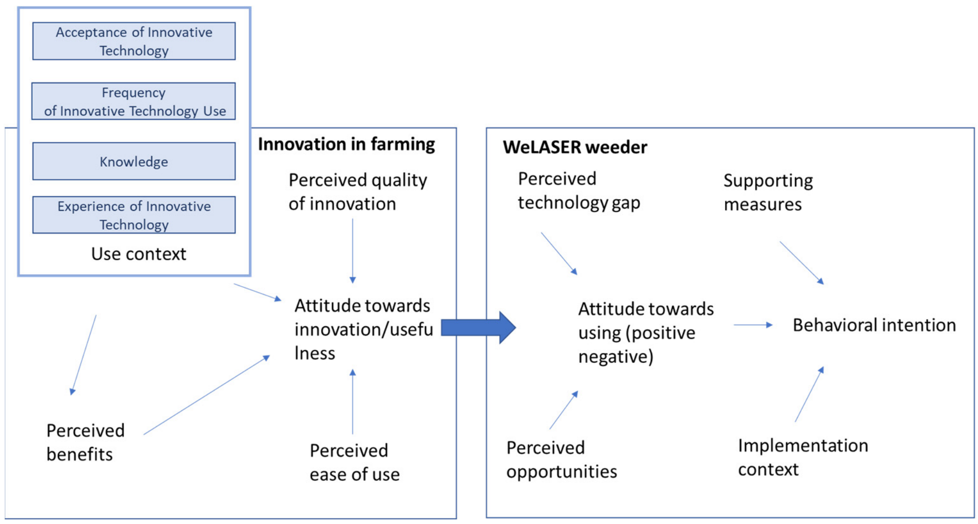

Figure 1. General concept of assessment.

The CATI method was chosen for the survey. The CATI survey of farmers was planned in three countries: Denmark, Spain, and Poland. The main criterion for the selection of countries was the level of development and technological advancement of agriculture: a modern and very efficient agriculture (Denmark, Spain) and a moderate level of development

(Poland), where the processes of technological transformation are slower. Based on the assumed objective of the CATI survey, the assumptions for the analysis and the number of cross-sections we would use to analyze the results of the survey were determined. The assumptions (sample selection criteria) we chose for the survey are as follows:

- Farmers are active in the production of field crops, vegetables, and horticulture.
- Cross section for farms of the surface over 1 ha: 50% of farms from 1 to 49 ha and 50% for farms over 50+ ha.
- Farmers have made modernization investments in their farms in the last 10 years.

Table 1. Conceptual framework—factors related to the adoption of novel technologies in general and of WeLASER in particular by farmers.

Factor	Main Aspect	Questions to Respondents	Relevant Innovation Studies and Theory
		Attitude to innovation in agriculture	
P1	Perception of enjoyment/usefulness/ attitude towards innovation	1. What is your attitude towards innovation in (defined as farming tools based on automation, advanced electronics, and communication through Internet and artificial intelligence) your own farm?	Attitude towards use [39]
P2	Ease of use of innovative technologies	2. What is your opinion on the ease of use of innovative technologies? Which of the following opinions would you subscribe to?	Technology Acceptance Model (TAM): perceived ease of use [40]
P3	Quality of innovation/reliability	3. How do you evaluate the reliability of innovative technologies (machines and implements) available on the market?	Technology Acceptance Model (TAM): sense of trust [41]
P4	Use context/attributes of the implementation system	4. Which attributes of your farm are important for use of innovative machinery?	[28]
P5	Perceived benefits/key drivers of implementation/impacts of the innovation	5. Do you see essential benefits in implementing innovative technologies?	[42]
		WeLASER application	
		Characteristics of the target population and market	
P6	Gap in knowledge and technology	Does it address preexisting needs in the farming systems? 6. Are you satisfied with the available weeding solutions in your work?	[42]
P7	Attitude towards use/expectations of end-users (positive)	7. What is your opinion about the WeLASER technology? Would you be interested in implementation of WeLASER technology in your farm?	[43]
P8	Attitude towards use/expectations of end-users (negative)	8. Why would you not decide to use the WeLASER technology?	[43]
P9	Opportunities of implementation	9. Which way of applying WeLASER in practice would be the most realistic from your point of view? (Please select only one answer)	Technology Acceptance Model (TAM): self-efficacy with agricultural machinery [44]
		Capability requirements and knowledge exchange	
P10	Implementation context/adaptation of on-farm practices and technology	10. What factors, in your opinion, may influence your decision?	[42]
P11	Supporting measures/human capital in innovation systems	11. What would convince you/farmers about the merits/use of WeLASER technology?	[42]
P12	Behavioral intention	12. Will you follow development of WeLASER as future application for your weeding control?	Technology Acceptance Model (TAM): behavioral intention to use [39,40]

For these parameters, a sample of at least N = 30 was obtained for large-, medium-, and small-sized farms in each country: Denmark, Poland, and Spain. If the sample size is larger than 30, we can use the z-test according to the statistical rules, where the test-statistic follows a normal distribution. In addition to these selection criteria for the sample, other parameters such as the type of farm, the age/gender of the farm manager, and the level of education were determined randomly so that cross-sectional analysis could also be carried out depending on the results. The sample N = 100 was planned as it offers a large scope to obtain results that allow a cross-sectional analysis (at the farm level) that is sufficient, with regard to the objective of the CATI survey. The following table shows the number of agricultural holdings in the three countries analyzed: Denmark, Spain and Poland (Table 2).

Table 2. Number of agricultural holdings by size and country.

Country	Number of Agricultural Holdings		
	from 0 to 49.9 ha	**50 ha and More**	**Total**
Denmark	24,110	13,260	37,370
Spain	842,530	101,780	944,310
Poland	1,390,040	31,520	1,421,560

The sample size (number of respondents n) for CATI research required to estimate a population proportion with a given confidence level and a desired margin of error is calculated as follows (1):

$$n = p \cdot (1 - p) \cdot \left(\frac{(z_{\alpha/2})}{E} \right)^2 \quad (1)$$

where p is the expected proportion (0.5 was used in the calculations to be on safe side), $z_{\alpha/2}$ is the critical value with a confidence level of 95% (1.96), and E is the desired margin of error (0.1).

With a sample of $n = 97$, the assumptions made above are fulfilled for farms of 0 to 49.9 ha and farms of 50 ha and more. Thus, a sample size of $n = 100$ is sufficient for carrying out a quantitative statistical analysis (for this n, the margin of error is $E = 0.098$).

In accordance with the conceptual framework, the questionnaire was developed in three parts:

- Profile of the interviewees;
- Section on perceptions of innovation in agriculture based on the farmer's own experience or views;
- Section on the evaluation of WeLASER implementation from a farmer's individual perspective.

Statistical Analyses of Data

As part of the WeLASER project, surveys were conducted with 100 respondents in 3 countries. As the data were mainly nominal, a cross-tabulation analysis was used to produce the results. Pearson's chi-square test was used to test the relationship between the two selected variables expressed on a nominal scale [45]. The Pearson chi-square statistic is calculated according to Formula (2):

$$\chi^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad (2)$$

where O denotes the observed values, E the expected values, i row index, and j the column index of the table. The test statistic from the above formula is approximately distributed as χ^2 with $(r - 1) \times (c - 1)$ degrees of freedom, where r is the number of rows and c is the number of columns. The *p-value* was calculated based on the χ^2 distribution value. The *p-value* indicates the probability that the null hypothesis H_0 is true for a given pair of variables. If the *p-value* is small enough, we reject the null hypothesis; if the *p-value* is high, the null hypothesis is not rejected. The significance threshold was assumed to be $\alpha = 0.05$. The test for independence can be expressed as follows:

H$_0$. *R and C are independent; there is no relationship between R and C; $O_i = E_i$;*

H$_1$. *R and C are dependent; there is a relationship between C and R; $O_i \neq E_i$.*

Here, *R* stands for rows, dependent variables; *C* for columns, independent variables; H_0 for the null hypothesis; H_1 for the alternative hypothesis; *Oi* for the observed values in cross-tabulation; and E_i for the expected values in the cross-tabulation.

In addition to the *p-value*, the upper limit for the Bayes factor $\overline{B}$ and was calculated (3). This is calculated for a given *p-value* and is a maximum coefficient that indicates how many times the alternative hypothesis H_1 is more likely to be true than the null hypothesis H_0. The upper limit for the Bayes factor $\overline{B}$ was calculated using the following formula [46,47]:

$$\overline{B} = -1/(e \cdot p - value \cdot \ln(p - value)) \tag{3}$$

Cramer's *V* was used to calculate the strength of the correlation between two cross-tabulated variables [48]. It is defined by the following Formula (4):

$$V = \sqrt{\frac{\chi^2}{n \times t}} \tag{4}$$

where *t* is calculated according to the following Formula (5):

$$t = minimum(r - 1, c - 1) \tag{5}$$

where *t* is the smaller result of the two subtractions and *n* is the number of respondents.

The Lee scale was used in the interpretation of Cramer's *V* coefficient [49]. Lee suggests the thresholds presented in the table below for interpreting the association.

Cramér's *V* Values	Association	Cramér's *V* Values	Interpretation
$V < 0.1$	negligible	$0.4 < V < 0.6$	relatively strong
$0.1 < V < 0.2$	weak	$0.6 < V < 0.8$	strong
$0.2 < V < 0.4$	moderate	$V > 0.8$	very strong

In addition, the z-test and the *p-value* were calculated for the comparisons of the column proportions. The Z statistics of z-test is calculated using the following Formula (6) [50]:

$$Z = \frac{dif}{SE_0} \tag{6}$$

where the numerator dif represents the difference between the column proportions and is calculated according to the following Formula (7):

$$dif = p_a - p_b \tag{7}$$

where p_a is the first proportion of a particular row in a given column and p_b is the second proportion of the same row in another column. The denominator SE_0 is the standard error for the difference under H_0 which is calculated using the following Formula (8):

$$SE_0 = \sqrt{\hat{p} \cdot (1 - \hat{p}) \cdot \left(\frac{1}{n_a} + \frac{1}{n_b}\right)} \tag{8}$$

where n_a and n_b denote the sample size of columns *a* and *b*. The notation $\hat{p}$ is an estimated proportion for both columns and is given by the following Equation (9):

$$\hat{p} = \frac{p_a \cdot n_a + p_b \cdot n_b}{n_a + n_b} \tag{9}$$

Under the null hypothesis, both columns' proportions have the same value, and it is equal to $\hat{p}$. After calculating the Z value and assuming that it follows a standard normal distribution, our *p-value* is calculated as 2-tailed significance using Formula (10):

$$p - value = 2 \cdot \Phi(Z) \tag{10}$$

where Φ denotes the standard normal distribution and Z represents the value of the z-test.

The Pearson chi-square statistic and Cramer's V association coefficient were calculated using the GNU PSPP 1.6.2 software [51]. Z-tests for the difference in column proportions were calculated using MS EXCEL 2019.

3. Results

3.1. Results of Tests for Existence of Association and Calculation of Strength of Association

A total of 300 participants took part in the survey, 100 each from Denmark, Poland, and Spain. The respondents had to answer 9 questions about themselves and 13 questions about their opinion. The questions describing the respondents and their farms are listed below.

Code	Question
S1	Which of the following statements best describes your role in farm decision-making?
S2	What type of production does your farm do?
S3	Have you modernized your farm in the past 10 years?
S4	Please specify the size of your farm's arable land area
A1	Size of farm expressed in 3 classes: 1–49 ha; 50–99 ha; 100 and more
S5	What is the type of cultivation system on your farm?
S6	How old are you?
A2	Age of farmer expressed in 3 classes: up to 39; 40–64; 65 and more
S7	Gender:
S8	What is your highest education level?
S9	What level of agricultural education you have?

The answers to the above questions were expressed on a nominal scale, with the exception of the answers to the questions on age and farm size. However, in further analyses, the data on age and farm size were expressed in three classes. Below is a list of key questions that describe respondents' opinions on the introduction of the new laser weed removal device. The key questions were developed according to the conceptual framework presented in Table 1. The list below was used for detailed analysis. For responses with multiple answer options, the most important ones were statistically analyzed (P4, P5, P9B, P10). There were also additional questions describing alternative preferences, such as "What is second or third most important to you?".

In the analysis, 4 questions from the first group and 12 key questions from the second group were selected for further analysis. The matrix below shows selected pairs of questions that were analyzed in the survey. A total of 110 pairs of relationships were analyzed (Table 3). The analyses were conducted separately for Denmark, Poland, and Spain.

The analysis was divided into two phases. The first phase involved (a) performing tests for the presence of a correlation by calculating the *p-value* of the Pearson chi-squared statistic, (b) assessing the strength of the correlation with the Cramer's V coefficient, and (c) calculating the descriptive statistics of these two parameters. The second stage involved a comparison of these parameters for Denmark, Poland, and Spain and the selection of data for further analysis.

The second phase involved analyses performed on the selected dataset, including (a) comparisons of column proportions for Denmark, Poland, and Spain for variables describing respondents' opinions, (b) examples of the calculation of cross-tabulations with significant association (α less than 0.05), and (c) analysis of cross-tabulation results for dominant responses and cross-tabulations with a *p-value* < 0.0005 (this is the maximum value calculated by the GNU PSPP software, which the program records as 0).

Code	**Question**
P1	Do you use innovation on your own farm?
P2	What is your opinion on the ease of use of innovative technologies? Which of the following opinions would you subscribe to?
P3	How do you evaluate the quality and reliability of innovative technologies (machines and specific implements) available on the market?
P4	Which attributes of your farm are important for use of innovative machinery? P4_1-1st most important:
P5	Do you see essential benefits in implementing innovative technologies? P5_1-1st most important:
P6	Are you satisfied with the weed control solutions available for your work?
P7	Is WeLASER weed control technology a good solution in your opinion?
P8	Would you be interested in implementation of WeLASER weeding control technology on your farm?
P9A	Which way of applying WeLASER weeding control technology in practice would be the most realistic from your point of view?
P9B	Why wouldn't you decide to use the WeLASER weeding control technology? P9B_1-1st most important:
P10	Thinking about buying WeLASER weeding control technology in the future, what factors might influence your decision? P10_1-1st most important:
P11	What would convince you or other farmers of the advantages of using WeLASER weeding control technology?
P12	Will you be following the further development of WeLASER weeding control technology as a potential future application on your farm?

Table 3. Matrix of performed analyses.

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9A**	**P9B**	**P10**
A1	X *	X	X	X	X	X	X	X	X	X	X
A2	X	X	X	X	X	X	X	X	X	X	X
S8	X	X	X	X	X	X	X	X	X	X	X
S9	X	X	X	X	X	X	X	X	X	X	X
P2	X										
P3	X	X									
P4	X	X	X								
P5	X	X	X	X							
P6	X	X	X	X	X						
P7	X	X	X	X	X	X					
P8	X	X	X	X	X	X	X				
P9A	X	X	X	X	X	X	X	X			
P9B	X	X	X	X	X	X	X	X	X		
P10	X	X	X	X	X	X	X	X	X	X	
P12	X	X	X	X	X	X	X	X	X	X	X

* X analyzed pair of questions

3.1.1. Results for Denmark

The table below shows the probability of not rejecting the null hypothesis (H_0) or rejecting the alternative hypothesis (H_1) for the Danish variables (Table 4).

Table 4. Results of the test on independence of key variables describing respondent profile and respondent opinions for Denmark.

	P1	P2	P3	P4	P5	P6	P7	P8	P9A	P9B	P10
A1	0.000	0.000	0.000	0.061	0.411	0.001	0.155	0.011	0.372	0.272	0.000
A2	0.005	0.081	0.049	0.956	0.000	0.021	0.894	0.127	0.004	0.182	0.686
S8	0.002	0.000	0.001	0.648	0.001	0.000	0.304	0.294	0.902	0.803	0.950
S9	0.001	0.000	0.053	0.504	0.216	0.556	0.629	0.313	0.800	0.398	0.965
P2	0.000										
P3	0.000	0.000									
P4	0.078	0.018	0.878								
P5	0.000	0.000	0.000	0.840							
P6	0.000	0.024	0.006	0.856	0.000						
P7	0.052	0.126	0.438	0.757	0.008	0.001					
P8	0.000	0.173	0.080	0.356	0.009	0.001	0.000				
P9A	0.160	0.872	0.023	0.591	0.566	0.070	0.569	0.010			
P9B	0.121	0.068	0.253	0.402	0.871	0.857	0.467	0.198	x		
P10	0.042	0.837	0.096	0.355	0.658	0.146	0.798	0.197	0.451	0.001	
P12	0.000	0.046	0.216	0.390	0.000	0.001	0.002	0.000	0.014	0.889	0.747

Source: Authors' calculation on the base of WeLASER project data.

In the case of Denmark, we have 46 pairs with a *p-value* of less than 0.05. There are also 36 cases with a *p-value* of less than 0.01 and 32 cases with a *p-value* of less than 0.005. There are 21 cases where the calculation of the *p-value* resulted in 0 (in reality it is <0.0005). From this, we can conclude that there is a correlation between the variables in 42.2% of the pairs analyzed (*p-value* < 0.05). The median of the *p-value* is 0.096, and the measure of variability, the median absolute deviation from the median (MAD), is 0.142.

The next table shows the strength of the relationships and presents the results of the Cramer's *V* calculation only for pairs of variables with a *p-value* of less than 0.05 (Table 5). Of the total of 46 pairs that met the selection criterion, 17 (37.0%) achieved a value of at least 0.4 (relatively strong association). The minimum Cramer's *V* value is 0.25. The median Cramer's *V* association coefficient for 46 pairs is 0.36, and the MAD is 0.074. The strongest associations are observed for pairs P1-A1 (0.69), P9A-A2 (0.62), and P1–P5 and P8–P9A (0.58).

Table 5. Results of the Cramer's *V* association of key variables describing respondent profile and respondent opinions for Denmark.

	P1	P2	P3	P4	P5	P6	P7	P8	P9A	P9B	P10
A1	0.69	0.58	0.44			0.37		0.31			0.40
A2	0.33		0.25		0.42	0.30			0.62		
S8	0.35	0.40	0.35		0.39	0.37					
S9	0.32	0.34									
P2	0.56										

Table 5. *Cont.*

	P1	P2	P3	P4	P5	P6	P7	P8	P9A	P9B	P10
P3	0.45	0.39									
P4		0.27									
P5	0.58	0.39	0.40								
P6	0.32	0.27	0.30		0.35						
P7					0.32	0.33					
P8	0.33				0.31	0.32	0.46				
P9A			0.47					0.58			
P9B											
P10	0.26									0.41	
P12	0.35	0.26			0.48	0.31	0.32	0.37	0.46		

Source: Authors' calculation on the base of WeLASER project data.

3.1.2. Results for Poland

Table 6 shows the probability with which the null hypothesis (H_0) is not rejected for the variables of Poland.

Table 6. Results of the test on independence of key variables describing respondent profile and respondent opinions for Poland.

	P1	P2	P3	P4	P5	P6	P7	P8	P9A	P9B	P10
A1	0.147	0.009	0.142	0.502	0.637	0.265	0.115	0.366	0.422	0.495	0.764
A2	0.333	0.055	0.855	0.041	0.391	0.436	0.291	0.306	0.832	0.089	0.240
S8	0.149	0.025	0.765	0.440	0.072	0.962	0.357	0.340	0.653	0.225	0.405
S9	0.317	0.206	0.867	0.887	0.301	0.976	0.457	0.208	0.647	0.857	0.457
P2	0.000										
P3	0.001	0.033									
P4	0.025	0.816	0.685								
P5	0.031	0.079	0.706	0.786							
P6	0.039	0.234	0.001	0.741	0.620						
P7	0.387	0.000	0.007	0.028	0.017	0.009					
P8	0.039	0.481	0.660	0.243	0.139	0.812	0.000				
P9A	0.351	0.371	0.008	0.689	0.769	0.331	0.701	0.726			
P9B	0.358	0.225	0.958	0.752	0.552	0.587	0.123	0.507	x		
P10	0.799	0.343	0.005	0.573	0.450	0.288	0.000	0.000	0.814	0.908	
P12	0.927	0.012	0.419	0.976	0.331	0.445	0.000	0.003	0.041	0.239	0.175

Source: Authors' calculation on the base of WeLASER project data.

In the case of the Polish part of the analysis, we have 25 pairs with a *p-value* of less than 0.05, 14 cases with a *p-value* less than 0.01, and 9 pairs with a *p-value* of less than 0.005. There are six pairs where the calculation of the *p-value* resulted in 0. From this, we can conclude that there is a correlation between the variables in 22.9% of the pairs (*p-value* < 0.05). The median of the *p-values* is 0.343, and the MAD is 0.436. The median for Poland is higher than that for Denmark.

The next table contains the results of the Cramer's *V* calculation for pairs of variables in Poland with a *p-value* of less than 0.05 (Table 7). In total, there are 22 pairs that fulfill this criterion. Three of them have a value of at least 0.4. The minimum value of Cramer's *V* is 0.24. The median of the Cramer's *V* association coefficient for 22 pairs is 0.31, and the MAD is 0.02. The three strongest associations are observed for the pairs P3–P9A (0.43), P9A–P12 (0.41) and P7–P12 (0.4). The median Cramer's *V* for Poland is higher than that for Denmark.

Table 7. Results of the Cramer's *V* association of key variables describing respondent profile and respondent opinions for Poland.

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9A**	**P9B**	**P10**
A1		0.32									
A2				0.31							
S8		0.30									
S9											
P2	0.37										
P3	0.33	0.26									
P4	0.30										
P5	0.30										
P6	0.24		0.33								
P7		0.33	0.29	0.29	0.30	0.30					
P8	0.27						0.38				
P9A			0.43								
P9B											
P10			0.32				0.35	0.35			
P12		0.28					0.40	0.30	0.41		

Source: Authors' calculation on the base of WeLASER project data.

3.1.3. Results for Spain

Table 8 shows the probability that the null hypothesis (H_0) is not rejected for the variables of Spain. In this case, we have 26 pairs with a *p-value* of less than 0.05, 12 cases with a *p-value* of less than 0.01, and 11 cases with a *p-value* of less than 0.005. In eight cases, the calculation of the *p-value* resulted in 0. We can conclude that there is a relationship between the variables in 23.9% of the analyzed pairs (*p-value* < 0.05). The median *p-value* is 0.256, and the MAD is 0.307. These values are higher than the corresponding values for Denmark and lower than the corresponding values for Poland.

Table 8. Results of the test on independence of key variables describing respondent profile and respondent opinions for Spain.

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9A**	**P9B**	**P10**
A1	0.253	0.224	0.034	0.327	0.836	0.411	0.335	0.594	0.537	0.096	0.762
A2	0.981	0.136	0.362	0.884	0.376	0.678	0.032	0.920	0.054	0.455	0.764
S8	0.934	0.731	0.059	0.312	0.194	0.172	0.889	0.339	0.463	0.367	0.233
S9	0.227	0.109	0.018	0.377	0.044	0.366	0.231	0.022	0.416	0.049	0.064
P2	0.021										
P3	0.220	0.873									
P4	0.085	0.015	0.369								

Table 8. *Cont.*

	P1	P2	P3	P4	P5	P6	P7	P8	P9A	P9B	P10
P5	0.000	0.862	0.000	0.134							
P6	0.466	0.887	0.215	0.033	0.613						
P7	0.000	0.927	0.097	0.027	0.015	0.000					
P8	0.005	0.048	0.845	0.000	0.083	0.003	0.000				
P9A	0.067	0.277	0.161	0.121	0.954	0.303	0.889	0.087			
P9B	0.787	0.568	0.444	0.411	0.963	0.385	0.956	0.430	x		
P10	0.426	0.352	0.700	0.231	0.332	0.010	0.240	0.176	0.256	0.463	
P12	0.069	0.600	0.045	0.584	0.130	0.001	0.000	0.000	0.002	0.391	0.774

Source: Authors' calculation on the base of WeLASER project data.

Table 9 shows the results of the Cramer's *V* calculation for pairs of variables with a *p-value* of < 0.05.

Table 9. Results of the Cramer's *V* association of key variables describing respondent profile and respondent opinions for Spain.

	P1	P2	P3	P4	P5	P6	P7	P8	P9A	P9B	P10
A1			0.26								
A2							0.29				
S8											
S9			0.29		0.30			0.27		0.45	
P2	0.27										
P3											
P4		0.30									
P5	0.39		0.40								
P6				0.30							
P7	0.33			0.29	0.32	0.34					
P8	0.29	0.26		0.35		0.32	0.37				
P9A											
P9B											
P10						0.30					
P12			0.27			0.34	0.59	0.42	0.49		

Source: Authors' calculation on the base of WeLASER project data.

At least 5 out of 26 (19%) scored 0.4. The minimum value of Cramer's *V* is 0.26. The median of the association coefficient of Cramer's *V* for 26 pairs is 0.31, and the MAD is 0.052. The strongest association is observed for the pair P7–P12 (0.59). The second strongest is observed for the pair P9A–P12 (0.49), and the third strongest for the pair P9B-S9 (0.45).

As a summary of the comparative analysis between Denmark, Poland, and Spain, a complementary statistical analysis of the *p-value* and Cramer's *V* coefficient was performed. The following table shows the descriptive statistics of the *p-value* and Cramer's *V* association coefficient for the analyzed countries. The Cramer's *V* statistics only include pairs with a *p-value* of <0.05 (Table 10).

In most cases, the variables representing both the *p-values* and the Cramer's *V* association coefficient do not conform to the normal distribution. For this reason, non-parametric estimators for location and dispersion (median, MAD) are more suitable than classical estimators (arithmetic mean and standard deviation).

Table 10. Statistics of *p-value* and Cramer's *V* association for Denmark, Poland, and Spain.

	p-Value			Cramer's *V*		
Country	**Denmark**	**Poland**	**Spain**	**Denmark**	**Poland**	**Spain**
Count	109	109	109	46	25	26
Minimum	0.000	0.000	0.000	0.250	0.240	0.260
Maximum	0.965	0.976	0.981	0.690	0.430	0.590
Mean	0.269	0.382	0.340	0.388	0.322	0.338
SD	0.322	0.307	0.310	0.103	0.047	0.079
SEM	0.031	0.029	0.030	0.015	0.009	0.015
CV	1.199	0.802	0.910	0.265	0.146	0.233
Skewness	0.926	0.354	0.693	1.144	0.683	1.690
Kurtosis	−0.639	−1.130	−0.772	0.898	0.115	3.092
Q1	0.001	0.079	0.059	0.320	0.300	0.290
Median	0.096	0.343	0.256	0.360	0.310	0.310
Q3	0.467	0.653	0.537	0.435	0.350	0.365
Q3-Q1	0.466	0.574	0.478	0.115	0.050	0.075
MAD	0.142	0.436	0.307	0.074	0.020	0.052
Distribution	not defined	not defined	not defined	lognormal	normal	not defined

Source: Authors' calculation on the base of WeLASER project data.

It can be observed that the median of the *p-value* for Denmark is lower than the median of the *p-value* for Poland and Spain, and the differences are statistically significant. The differences between Poland and Spain are rather small and not statistically significant. The MAD (median absolute deviation) of the *p-value*, which in this case is an indicator of dispersion, varies similarly to the median. The lowest MAD is observed in the case of Denmark, while it is much higher in Poland and Spain, with Poland being slightly higher than Spain. In all cases, the MAD is higher than the median.

For Cramer's *V* coefficient, we can see that the parameters of location of Cramer's *V* for Denmark are higher than their counterparts for Poland and Spain (both medians and means). The differences in the medians of Cramer's *V* between Denmark and the other two countries are statistically significant. The differences in the medians of Cramer's *V* between Poland and Spain are small and not statistically significant. Poland has the lowest variability in the Cramer's *V* association coefficient expressed in standard deviation, while Denmark has the highest Cramer's *V*.

3.2. Comparisons of Column Proportions for Denmark, Poland, and Spain

This part of the results refers only to variables that reflect the opinions of the respondents. The results of the column comparison proportions are shown in the following table. The frequencies of occurrence of differences with a *p-value* of < 0.1 and a *p-value* of < 0.05 were calculated, and the results are shown in the following table (Table 11).

Table 11. Results of column proportion comparison for Denmark, Poland, and Spain.

α	**Denmark**		**Poland**		**Spain**		**3 Countries**
	Count	**%**	**Count**	**%**	**Count**	**%**	
<0.05	28	27.72	39	38.61	34	33.66	101
<0.10	26	26.26	45	45.45	28	28.28	99
Total	54	27.00	84	42.00	62	31.00	200

Source: Authors' calculation on the base of WeLASER project data.

It should be noted that the total number of significant differences in the column proportions is 200, and the number of differences with α less than 0.05 (101) is generally the same as with α less than 0.10 (99). In contrast to the results of the previous parameters (*p-value* and Cramer's *V*), the highest number of significant differences concerns Poland, and the lowest concerns Denmark. And this applies both to the total number of differences and to the differences at both α-levels.

Examples of cross-tabulations with significant correlation (α less than 0.05):

There are nine common pairs for all three countries, five of which have a mean value of Cramer's *V* greater than 0.4 (relatively strong association). These are P9A–P12 (0.475), P1–P5 (mean value of Cramer's *V* is 0.423), P7–P12 (mean value is 0.420), P7–P8 (mean value is 0.415), and P1–P2 (0.415). The other remaining pairs are P8–P12, P6–P7, P5–P7, and P1–P8.

For reasons of conciseness, only one pair of questions was selected for a more detailed description, namely P1–P2. The cross-tabulation is made up of two questions: In the columns, P1 represents an independent variable. The question P1 is as follows: "Do you use innovation on your own farm?" The possible answers are as follows: (A) I already use innovation on my farm; (B) I am considering using innovation; (C) I do not use, but I am interested in it; (D) I do not use, and I am not interested in it; (E) Hard to say. The dependent variable P2 is the following question: "P2. What is your opinion on the ease of use of innovative technologies? Which of the following opinions would you subscribe to?". The possible answers are as follows: (i) I find it easy to implement innovative technologies on my own; (ii) Implementing innovative technologies requires me to acquire new skills and knowledge, but it is not a problem for me; (iii) I think it would be a problem for me to acquire new skills and knowledge, but I can do it; (iv) Implementing innovative technologies is a problem for me and I have to rely on external support and advice; (v) I don't know/I have an opinion.

Below, the contingency table shows the number of cases for each pair of answers for Denmark. The number of cases also indicates the percentage, as we have exactly 100 cases in total (Table 12).

Table 12. Cross-tabulation of P1 and P2 questions for Denmark.

	A	**B**	**C**	**D**	**E**	**Total**
i	12	0	0	0	0	12
ii	29 C *	4	7	0	0	40
iii	3	3	21 A *	0	0	27
iv	0	0	11	1	0	12
v	0	1	1	5	2	9
Total	44	8	40	6	2	100

Source: Authors' calculation on the base of WeLASER project data. * The capital letter at the number represent significance of *p-value* of Z statistics below 0.05.

In the case of Denmark, the calculated *p-value* of the Pearson chi-squared statistic is 0 (less than 0.0005), and the Cramer's *V* coefficient is 0.56. From the table above, it can be deduced that 44% of respondents already use innovations on their farms, and 40% do not use them but are interested in doing so. From this, it can be concluded that for those who use innovations, it is not a problem to introduce innovative technologies themselves (12 cases and all answers A in group "i"). It should be noted that there is a significant difference in the column proportions for the group in row "ii" between columns A and C. The *p-value* of the z-test is less than 0.05, which means that the proportion of A responses is significantly higher than the proportion of C responses. The opposite result is observed for row "iii", where the proportion of C is significantly higher than the proportion of A.

The next contingency table shows the answer pairs for Poland (Table 13).

Table 13. Cross-tabulation of P1 and P2 questions for Poland.

	A	B	C	D	Total
i	19	2	0	0	21
ii	34 bcD *	7	9	1	51
iii	9	1	2	4	16
iv	2	1	3	5	11
v	0	0	0	1	1
Total	64	11	14	11	100

Source: Authors' calculation on the base of WeLASER project data. * The capital letter at the number represent significance of *p-value* of Z statistics below 0.05. The lowercases represents significance of *p-value* of Z statistics between 0.05 and 0.1.

In the case of Poland, the calculated *p-value* of the Pearson chi-squared statistic is 0, and the Cramer's V coefficient is 0.37. We can see that no one answered "Hard to say" to question P1, so column E was omitted. From the table for Poland, we can deduce that 64% of respondents already use innovation on their farms.

For 51% of respondents, it is not a problem to introduce innovative technologies, even if this requires the acquisition of new skills and knowledge. In this group of respondents (answer "ii"), we observe significant differences in the column proportions. The proportions of column A are significantly higher than those of columns B, C, and D. But only the difference between the proportions of columns A and D is significant at α equal to 0.05. For the remaining two differences (marked with small letters), the significance level α is 0.10.

The next contingency table presents pairs of answers for Spain (Table 14).

Table 14. Cross-tabulation of P1 and P2 questions for Spain.

	A	B	C	D	E	Total
i	9	1	0	1	0	11
ii	25	1	6	5	2	39
iii	6	3	3	1	0	13
iv	30 CD *	0	4	2	0	36
v	0	0	0	1	0	1
Total	70	5	13	10	2	100

Source: Authors' calculation on the base of WeLASER project data. * The capital letter at the number represent significance of *p-value* of Z statistics below 0.05.

In this case, the calculated *p-value* of the Pearson chi-squared statistic is 0.021, and the Cramer's V coefficient is 0.27. We can see that 70% of respondents already use innovations on their farms. About half of them do not see a major problem in introducing innovations, while the other half see problems and need to rely on external support. In the case of Spain, the group of respondents who see a problem with the introduction of innovative technologies is the most numerous (30% of all respondents). In this group (represented by row "iv"), the proportion of those who already use innovations clearly exceeds the proportion of those who do not use innovations (columns C and D). However, there are slight differences in the significance level of the difference in the column shares between A and C and between A and D. The first value corresponds to α equal to 0.05, and the second to α equal to 0.10.

3.3. The Predominant Responses in Selected Cross-Tabulations for Variables Describing Respondents' Opinions

In this part of the analysis, we looked at individual crosstabs. We selected crosstabs with a *p-value* of the χ^2 statistic of less than 0.0005. At this *p-value*, the alternative hypothesis H_1 is at most 96.8 times more likely than the null hypothesis H_0.

A total of 27 crosstabs fulfill the above criterion, 13 from Danish crosstabs, 6 from Polish crosstabs, and 8 from Spanish crosstabs. Each crosstab consists of $r \times c$ crossings (number of rows times number of columns), which represent pairs of answers. The dominant crossings, that is, dominant pairs of responses, are described below.

Denmark

Denmark's first cross-tabulation with a *p-value* of 0 is the cross-tabulation P1–P2, which consists of 25 intersections. We can see that the dominant group with 29% are the respondents who already use innovation on their farm and believe that it is easy to introduce innovative technologies themselves.

In the next cross-tabulation, P1–P3, which consists of 20 intersections, the respondents who already use innovation on their farm and believe that innovative technologies are generally of good quality and reliable dominate with 42%.

In cross-tabulation P1–P5 (30 intersections), the group of respondents who already use innovations on their farms and believe that the introduction of new technologies brings significant economic benefits (cost reduction, higher income) dominates with 27%.

The results of cross-tabulation P1–P6 (25 intersections) show that the dominant group, which accounts for 31% of respondents, already uses innovations on their farms and is quite satisfied with the available weed control solutions.

The cross-tabulation P1–P8 (25 intersections) is dominated by 27% of respondents who do not use the innovation on their farm but are interested in it and would be willing to use WeLASER weed control technology but believe that it only partially solves their weed control problems.

The cross-tabulation P1–P12 (25 intersections) shows that the predominant group, accounting for 29%, are farmers who already use the innovation on their farms and are very willing to pursue the further development of WeLASER weed control technology as a possible future application on their farm.

In cross-tabulation P2–P3 (20 intercepts), 31% of respondents (the dominant group) believe that the introduction of innovative technologies requires the acquisition of new skills and knowledge, but have no problem with this. This group also believes that the innovative technologies available on the market (machines and specific tools) are generally of good quality and reliable.

The cross-tabulation P2–P5 (30 intersections) is dominated by the 20% of respondents who believe that the introduction of innovative technologies requires the acquisition of new skills and knowledge, but this is relatively easy to accomplish. They also believe that the introduction of innovative technologies brings significant economic benefits (cost reduction, higher revenues).

The cross-tabulation P3–P5 (24 intersections) shows that 34% of respondents (the dominant group) generally consider innovative technologies to be of high quality and reliable and that these technologies bring considerable economic benefits.

In cross-tabulation P5–P6 (30 crosses), 35% of respondents believe that innovative technologies have significant economic benefits, while they are unlikely to be satisfied with available weed control solutions.

The cross-tabulation P5–P12 (30 intersections) shows that the predominant group, accounting for 31% of respondents, are those who believe that innovative technologies have significant economic benefits and at the same time believe that they will pursue further development of WeLASER weed control technology as a possible future application on their farm.

The results of cross-tabulation P7–P8 (20 intersections) show that 26% of respondents (the dominant group) think that WeLASER weed control technology seems to be a good solution and are interested in using WeLASER weed control technology on their farms, even if they think it will only partially solve their weed control problems.

In the final Danish cross-tabulation P8–P12, which consists of 25 intersections, respondents who believe that WeLASER will only partially solve their weed control problems are the dominant group with 29%, although they are interested in implementation and believe that they are likely to follow the further development of WeLASER.

Poland

The first cross-tabulation for Poland with a *p-value* of 0 is the cross-tabulation P1–P2, which consists of 20 cross-points. We can see that the dominant group with 34% are the respondents who already apply innovations on their farm and believe that it is easy to introduce innovative technologies themselves.

The second cross-tabulation for Poland, P2–P7, consists of 25 intersections. The dominant group, accounting for 33%, are respondents who believe that the introduction of innovative technologies requires the acquisition of new skills and knowledge, which is not a problem, while at the same time, they believe that WeLASER weed control technology is a good solution.

A further cross-tabulation of P7–P8 (30 intersections) shows that 35% of respondents (the dominant group) think WeLASER weed control technology is a good solution and are rather interested in implementing WeLASER, although they believe it will only partially solve their weed control problems.

The cross-tabulation P7–P10 (25 intersections) shows that 24% of farmers (the dominant group) think that WeLASER seems to be a good solution and that the most important factor influencing the decision to purchase WeLASER weed control technology is the availability of public support.

The results shown in cross-tabulation P7–P12 (25 intersections) show that the dominant group, representing 39% of respondents, considers WeLASER to be a good solution and is likely to follow the further development of the technology.

The final cross-tabulation for Poland, P8–P10 (30 intersections), shows that 23% of respondents (the dominant group) are rather interested in using WeLASER weed control technology even if it cannot solve all weed problems and that they believe that the most important factor influencing the decision to purchase WeLASER weed control technology is the availability of public support.

Spain

The first cross-tabulation for Spain with a *p-value* of 0 is the cross-tabulation P1–P5, which consists of 35 intersections. The predominant group, accounting for 37%, are respondents who already use innovation on their farms and believe that the most important benefit of introducing innovative technologies is the improvement of working conditions.

In the second cross-tabulation for Spain, P1–P7 (25 intersections), the dominant 55% of respondents already use the innovation on their farm and think that WeLASER appears to be a good solution.

In cross-tabulation P3–P5 (28 intersections), 37% of respondents (the dominant group) believe that the innovative technologies available on the market (machines and specific tools) are generally of good quality and reliable and that the main significant benefit of introducing innovative technologies is that they improve working conditions.

In cross-tabulation P4–P8 (30 intersections), 21% of farmers (the dominant group) believe that the most important factor influencing the possible use of innovative machinery is the structure of agricultural land (subdivided plots), and they consider this technology very useful for weed control (they are interested in adopting WeLASER weed control technology).

In cross-tabulation P6–P7 (20 intersections), 47% of respondents (the dominant group) are rather satisfied with the weed control solutions available to them in their work, and for them, the WeLASER weed control technology seems to be a good solution.

Cross-tabulation P7–P8 (25 intersections) shows that for the dominant group, representing 33% of respondents, WeLASER weed control technology seems to be a good solution, and they would definitely find this technology useful for weed control and are interested in using WeLASER weed control technology on their farm.

In cross-tabulation P7–P12 (25 intersections), the dominant group, representing 43% of respondents, believes that the WeLASER weed control technology seems to be a good solution and that they will definitely follow the further development of WeLASER.

In the last crossover table for Spain (with *p-value* = 0), P8–P12 consisting of 25 intersections, the dominant group, representing 40% of the respondents, would definitely find the technology useful for weed control, is interested in using WeLASER technology for weed control on their farm, and will definitely follow the further development of the WeLASER weeder.

4. Discussion

The results obtained show meaningful patterns in relation to the three groups of questions: respondents' profiles, experiences and attitudes towards innovation in agriculture, and attitudes towards laser-based weed control solutions such as the WeLASER weeder within the regional context. Significant differences are observed between countries.

Denmark

It can be observed that innovations in Denmark are implemented by well-established farmers who generally have a higher education. The use of innovations is associated strongly with farm size with large farms predominating and to a lesser extent with the age of the farmer. The use of innovation was mostly reported by middle-aged and highly educated farmers, with 43% of those respondents already using innovation and 7% of those considering innovation.

The results show that farm size determines the experience and socio-economic potential of adopting innovative techniques. According to Danish farmers, the key factors are the ease of use of these technologies, their quality, and their potential benefits. These attributes are strongly associated with the farm size with the exception of the perception of benefits. Of the farmers who use innovation, 12% find it easy to use, and 29% state that it is not a problem to learn new technology, even if it requires new skills. For 40% of all respondents, it is also a relevant answer, and 27% state that additional assistance is required. It can be deduced from this that advanced farming in well-established farms run by experienced practitioners is a strong factor in innovation adoption. Farmers who are experienced in using innovation also see significant advantages in their implementation, as reported by around 44% of those who already use innovations (31% of all respondents), 8% of those who are considering using them, and 40% of those who are interested in using them (45% of all respondents). The main benefits cited were working conditions and economic advantages. This is in line with studies from the United States, where farm size, computer skills, full-time farming employment, farm type, and farm location were cited as key factors for adopting PA [52].

A high level of satisfaction with weed control is observed among Danish respondents (rather satisfied—46%), although the predominant response indicates some uncertainty. Farmers' views on weed control measures are strongly associated with the current experience of using innovation in general, the positive assessment of the reliability and quality of innovations, and the perception of their benefits. Farmers who are rather satisfied with the weed control solutions on their farms see the benefits of innovative techniques in the improvement of working conditions (17%) and in significant economic benefits (35%). These respondents perceive the innovative techniques to be usually of good quality and reliable (68% (42% of all respondents)). This indicates that the quality expectations of farmers are quite high and also place high demands on weed control methods.

In the Danish data, the association between the use of innovation on farms and the opinion on the potential use of the WeLASER weeder is rather weak, or no relevant association is found. For example, the perception of the good quality of the innovation is not associated with the willingness to adopt WeLASER. The majority of these farmers do not perceive the WeLASER weeder as an important technology for their farm (39.4% of responses were that the weeder is probably or definitely not useful for their farm).

Only 11% expressed the view that they might rather implement the technology, although it will not solve all the weed problems. This can be explained by the fact that different farming practices and economic and structural circumstances determine their perception. Furthermore, the high level of satisfaction with current practices does not encourage them to look for more radical solutions.

Although farmers are generally positive about WeLASER technology, there is a certain reluctance to formulate their opinion about its application in their practice. Most of the respondents expressed the view that it is "hard to say" whether WeLASER is a good solution (54%). For 35% of all respondents, it seems to be a good solution. The majority of these farmers expressed interest in the implementation of the WeLASER weeder but saw it as only a partial solution to weed problems (90% of all respondents). The reluctance towards the technology can also be explained by the fact that there are not yet many applications of the robot that have been tested in practice, although the farmers' curiosity and expectations are obvious. Of the respondents who do not use innovations, 24% are interested both in innovations in general and see a potential for WeLASER weeder introduction. The uncertainty is also reflected in the strong association between the answers on the satisfaction with the current weed control solution, "rather satisfied", and the use of WeLASER, "rather WeLASER can partially solve the problems". The general reluctance is most likely related to the lack of specific information as 82% of Danish respondents stated that they need more reliable and accurate information about the technology in order to eventually implement it in their practice. This is in line with other studies where the performance expectation factor should be increased by better communication [43].

Farmers who rated WeLASER technology as a suitable solution for their farm indicated renting of services (35%), purchase with external funding (25%), joint purchase (15%), and renting without service (10%) as options for adoption. Potential interest ("probable") in further developments of the WeLASER weeder was expressed by both young and middle-aged farmers.

Poland

Predominantly, middle-aged farmers use innovation in agriculture, but in terms of farm size, there is an even split between small, medium, and large farms without strong prevalence towards any category. This can be explained by the high proportion of medium-sized farms (up to 49 ha) in the study. This is partly consistent with other studies in Poland which have observed that precision farming techniques are more popular with farmers who are younger than 40 years old, have higher education, and run large farms [53,54].

In Poland, the farm scale and the use of innovation were also identified as significant factors in the perception of innovation adoption. There is a statistical association between the size of farms and the perception of ease of use. Of the respondents, 51% perceive technologies as requiring additional skills and knowledge and state at the same time that it is not a problem for them to learn how to operate them. In this group, 60% of farmers run small farms. In addition, 21% of all respondents can implement technology themselves. A higher level of education can be observed in these two groups. This suggests that there is no specific barrier in terms of ease of technology implementation related to farmers' knowledge and experience, but that there is a general openness towards new technologies. Nevertheless, these results suggest that the strengthening of knowledge transfer and education especially among small holders as well as the development of appropriate advisory services should be promoted in Poland.

The quality of the innovative technology is also a key factor for Polish farmers. Farmers who already use the innovation rate it as "usually of good quality" (51% of respondents). For all respondents, the figure is 72%, compared to 15% who think that it is are "usually of bad quality". The positive perception of the quality of innovative techniques is also associated with the level of satisfaction with weed control on farms. The proportion of responses stating that "they are of good quality" and that the "weed control measures are satisfactory" is 50%, For all respondents, the proportion is 72%. This can be interpreted as a generally positive experience and attitude towards innovation, and this opinion applies to weed control methods.

The perception of WeLASER technology as a good solution is related in strong statistical terms to key features of innovative technologies perception: quality, ease of use, benefits, and satisfaction with weed control. It is also associated with willingness to adopt this technology, but previous positive experiences with innovation do not have a major influence on the willingness to adopt the WeLASER weeder. This discrepancy can be explained by the fact that there may be significant limitations to the use of the weeder. For example, 35% of respondents who perceive the WeLASER weeder as a good solution would potentially use this technique a as technology only "partially solving weeding problems" (48% of all respondents). At the same time, 33% of respondents who would use the robot as a partial measure are satisfied in general with the weed control currently applied (48% for all). In contrast, 34% of respondents see no reason to definitely or probably use the technology on their farms.

The perception of the good quality of the WeLASER weeder and the willingness to implement it are also related to the willingness to follow the further developments of the WeLASER project and a strong opinion on the key factors for implementation. Most of the respondents (46%) indicated public support as the main factor, and 31% indicated more stringent policies. Public support was particularly emphasized by smaller holders. This also confirms that WeLASER technology can be adopted by farmers who have better financial strength and more favorable conditions and opportunities for adoption.

There is uncertainty regarding the introduction of the WeLASER weeder as the perception of the suitability of WeLASER technology would require the development of new skills (33% of all respondents). The perception of suitability (WeLASER as a partial solution) with 58.8% of those who rate WeLASER weeder positively indicates significant potential on the one hand and the existence of barriers to application on the other.

Among the farm attributes for the introduction of innovative technology, the financial situation of the farm was indicated by farmers (45% of all respondents) as the most important. This opinion was mainly expressed by the middle-aged and young farmers. Reliable and accurate information on the performance of the technology, including costs and benefits for specific crops, was mentioned by 57% of all respondents.

Spain

According to Spanish farmers already using innovation, the quality and perception of benefits seem to be strong factors for implementation. Of all respondents, 79% answered that innovative techniques are "usually of good quality", and 15% that they are "always of good quality". In the first category of responses, 37% indicated improved working conditions as the main benefit (46% of all respondents), and 14% cited increased productivity. In terms of the ease of innovation, there is a clear split into two groups: those who perceive innovation as "requiring new skills, but being not problematic" (25% of all respondents) and those who "require external support and advice" (30% of all respondents).

The acceptance of WeLASER technology as a good solution is high. This is evident among respondents who already use innovation—for 55% of respondents, it is a potentially good solution, and for 11%, it is "definitely a good solution". For all respondents, these figures are 72% and 17%, respectively. At the same time, 38% of respondents who use innovation consider WeLASER technology to be definitely useful for weed control (46% of all respondents), and 17% see it as a solution that only partially solves the weed problem (21% of all respondents).

In Spain, there is a strong association between the expressed dissatisfaction with weed control practices and the positive evaluation of WeLASER technology and the willingness to adopt it. Most of the farmers who expressed an interest in introducing the WeLASER weeder are rather dissatisfied (17%) or rather satisfied (26%) with weed control. Among the respondents who indicated that WeLASER can only partially solve their problems, these figures were 6% and 12%, respectively. At the same time, 66% of respondents who are not satisfied or are rather satisfied with weed control solutions currently in use consider

WeLASER technology to be a good solution, and 15% consider it to be a definitely good solution. The potential adopters at the same time use the innovations in their practice, perceive the importance of the specific conditions of the farm, and see significant advantages of these technologies. These results are quite unique among the countries surveyed and show a strong need for new solutions.

Another unique feature is that the Spanish farmers who responded positively to the introduction of WeLASER technology (81.2% of all farmers) indicated the structure of the land (fragmented plots) as the potential main barrier. Only 15.4% cited financial condition as the main factor. The farmers' expectations are obviously high as most of them are willing to follow the further development of WeLASER technology.

Country comparison

In the survey, only the following attributes of the respondent profile were relevant: size of the farm, age of the respondent, level of general and vocational education. In all countries, mostly male farmers responded to the questionnaire. In all countries surveyed, the positive perception of innovation in the general responses and the attitude towards WeLASER essentially reflect the agricultural structure. For example, in Poland, innovation is adopted in all size classes.

Other studies point to farm size but also to the cultivation system (organic/conventional) and the occupational structure (part-time/full-time) as relevant characteristics that influence the evaluation of the advantages and disadvantages of field crop robots [28,55,56]. This also agrees with the conclusion that in Denmark, the well-established farms in terms of their economic position and experience are the most innovative.

Although the current experience with innovative solutions is positive in all the countries studied, the application of the WeLASER weeder is a challenge as expectations regarding the quality of the device are high.

In Denmark, the country with the most experience in precision agriculture, the answers to the questions were more consistent than those in the other countries, which can be interpreted as a result of greater experience with the use of innovative solutions than in Poland and Spain. It should be emphasized that Danish farmers were more skeptical and more demanding of reliable proof of WeLASER performance. A German case study also shows a moderate influence of previous experience on further technological advancements [42].

The results suggest that farmers in Poland and Denmark were more confident in adopting new techniques on their own or by developing new skills than those in Spain, where the need for external advice and support was more strongly expressed. From this point of view, as shown in other studies [57], holistic services in areas with low precision agriculture adoption have to be promoted. In this context, studies in the US have identified barriers to the provision of precision agricultural services such as equipment and costs that reduce the profitability of services related to precision agriculture [58]. A further recommendation is the provision of simple operational procedures to support the transition to precision farming solutions [19] and to strengthen the training and education of farmers, especially for owners of smaller farms [17].

It should be emphasized that the farmers in all countries surveyed pointed out social aspects (working conditions) and to a lesser extent economic aspects (higher profitability) as the key benefits of using innovation in agriculture. This is in contrast to some other studies that emphasize the economic factors [59], but other studies [42,43] also point to the reduced workload as an important factor. The environmental aspect was perceived as the least important, although various studies point to many related advantages of precision agriculture [60,61]. This could be reflected in the respondents' perception of the legal requirements for the use of herbicides. The economic feasibility of the technology, national policies, and the resulting legal situation are also mentioned in other studies [42]. It is assumed [62] that policy inducements could change the relative input/output prices faced by farmers to encourage the adoption of precise technologies.

The results from all countries indicate that the WeLASER technology can be used primarily as a complementary solution and not as a stand-alone technique, as most of the respondents stated that the WeLASER weeder can only partially solve their weed control problems. Furthermore, as other studies show, other PA techniques should be used to increase the effectiveness of weed control [63]. It should also be noted that the innovative techniques may not be relevant for all farms depending on the specific conditions [64]. These results indicate that the development of commercialized versions of WeLASER-based machines should take into account certain flexibility in designing technical solutions to allow a better adaptation of the solution to the farmers' needs. Opportunities should be created to integrate WeLASER technology with other weed control methods. For example, there are possibilities for providing separate laser weeding implements that can be easily adapted to current farming practices.

In all countries, there is a reluctance to introduce this technology, as it is a novelty and many aspects need to be resolved before commercialization and practical use. This is consistent with a strong notion that farmers will not adopt a technology until it meets their needs. Other studies have found that most agricultural innovations were conceived on-farm and then commercialized by companies [65]. At the same time, the results indicate an openness towards WeLASER technology. Spanish farmers are the most likely to see it as a potential technology for solving their weed control problems.

In each country, there is a clear group of potential adopters characterized by consistency in the responses regarding the quality of the WeLASER weeder, its suitability (partial application), and willingness to pursue further developments. Similarly, a very positive attitude towards the innovation process has also been observed [66] in user groups that have already oriented themselves and adapted all production factors to innovative change.

There are considerable differences of opinion regarding the business models of implementation. In Spain, the prevailing opinion was that the best business option for farmers is weeding machinery rental; in Poland, purchase with non-repayable subsidies; and in Denmark, rental of services and also joint purchasing and purchasing with external financing. In comparison, options such as contractor services and machine sharing were identified as the preferred modes of robot deployment in Bavaria, Germany [28]. The results indicate that there should be well-targeted commercialization approaches that take into account country and regional specificity. It is recommended to support customized business models within the framework of national agricultural policies.

Public support was indicated as an important factor for the introduction of WeLASER technology in all countries, by 45% of respondents in Denmark, 46% in Poland, and 41% in Spain, but in Denmark and Spain, there were also other factors mentioned as important, especially labor market conditions and food quality. In Poland, 31% of respondents also indicated agricultural and policy requirements. This is in line with European policy recommendations on delivering tools and incentives especially for small- and medium-sized farms to facilitate the adoption of innovative technologies [67–69].

In all countries, farmers pointed out that they need reliable and accurate information on the performance of the technology and the costs and benefits of its application in practice (Denmark—82% of respondents; Poland—57%; Spain—36%). This is also underlined in other studies. Robot suppliers should better inform farmers about the performance of their products, for example by involving farmers in the process of robot development [42] and by demonstrating the main benefits in practice [70]. According to other studies, the information must be provided by the manufacturers/dealers of robots [42] and by the institutions responsible for advising farmers on their practices [71]. The adoption of a new technology is a process that starts with farmers knowing that it exists, then forming favorable opinions that lead to adoption, and then having the intention to try it based on their research findings [1]. The opportunity and experience of using PA technologies on other farmers' fields increases the likelihood of adopting these technologies [72]. The positive influence of counseling on the adoption rate was observed in a study in the US [55]. The need for improved information, financial support mechanisms including more accessible subsidies, and the provision of services along with reliable implementation and aftercare support was also indicated as an important factor for adoption in less technologically advanced regions and countries [73].

5. Conclusions

This study identified key aspects of the implementation of laser-based weed control technology from the perspective of farmers. Farmers in three countries were interviewed using the CATI method. The results were analyzed using statistical methods to (1) determine the relationship (association probability) between the respondents' profile and the perceptions of innovation and attitudes towards WeLASER weeder implementation in their farming practice and (2) gain insight into how farmers' perceptions of innovation influence their attitude towards WeLASER technology implementation based on their experiences.

Based on the results, certain patterns can be distinguished in the responses indicating that there are groups of potential adopters in all countries who positively perceive innovative techniques and formulate expectations for the WeLASER weeder. The results show that the highest potential exists in larger farms operated by young and middle-aged farmers. This is in line with other studies on the acceptance of new technologies in agriculture [74]. In Spain and Poland, owners of smaller farms also see a reason for the adoption of laser-based weed control tools. The results also show that there are not many early adopters in the samples studied.

A high level of confidence in the potential implementation of WeLASER technology is observed in all countries as there is a high number of farmers for whom the application of an innovative technology is not a problem and who can learn how to use it themselves. Nevertheless, there is a need for supporting services and advice, especially in Spain. It is advisable to provide good assistance and service for the users of this technology.

In the future development of this technology, care should be taken to ensure that the high quality of the technology meets the expectations of farmers. It can also be suggested that the functionality of the technology be extended as it is seen as a partial solution to weed control problems faced by farmers.

The introduction of a laser-based weed control tool in agricultural practice should be supported by providing funding but also by facilitating other forms of its use (leasing, renting, sharing).

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