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*Article*

# Potential of Eco-Weeding with High Power Laser Adoption in 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 transitions. Weeding is one of the most important factors of agricultural production. New weeding techniques are being developed to enhance sustainability. Among them laser based weeding seems a promising alternative for use of chemicals. WeLASER technique is a novel technique of weed control. Its successful implementation depends on many factors related to the innovation itself, policy context, farming conditions and users' attitudes. Survey was carried out to provide the insight on the attitudes toward the innovative (laser) weed control tool (device - autonomous robot). The CATI method was selected for the survey of farmers opinion and carried out in three countries: Denmark, Spain and Poland. Statistical methods were applied to analyze the results. The study provided knowledge on how farmers see the barriers and opportunities of implementing the device in practice. Positive attitudes of farmers were observed but with high expectations related to quality of the technique and systemic conditions of its implementation.

**Keywords:** Laser; weeding technique; autonomous robot; sustainable agriculture; CATI survey

## 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 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], and also goals of the long-term Vision for the EU's Rural Areas [5]

Sustainability of the agricultural sector depends in many ways on its further advancements in 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 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 digital transformation of agriculture by using sensors on machines to detect actual soil and crop information (weed recognition, amount of biomass, nutrient status, pests, diseases), yield mapping for success control of variable rate applications and communication protocols and cloud connectivity to facilitate data flow [2,9–15]. There is increasing role that knowledge and information play in obtaining control of resources, increasing profits, and reducing risk in farming [16,17].

There are many benefits for farmers of Precision Agriculture. It improves productivity and profitability of the farm, automation of machines operations, improves comfort, lower $CO_2$ footprint and water contamination with nitrate and pesticides, improvement of public image of farming. Use of Hi Tech can attract young people for farming and keep them in rural areas [2,18].

Precision agriculture help farmers to adjust to policy requirements concerning environmental protection. The use of herbicides on organic farms is banned in Europe [19–22] stimulating changes

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in the crop production systems.. In addition, consumer habits are forming and there is growing concern about access to safe food.

Adopting sustainable agriculture techniques that boost 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 can be also expected that problematic weed management (due to herbicide resistance, lower efficacy of chemicals due to timing of application, weather-indicated lower efficacy) is also acting as a driver for adoption of none chemical solutions [24,25].

Weeding is one of the most important factors in agricultural production. Weeds can lower essentially the productivity in the 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 include laser based weeding. Laser based weeding seems a promising alternative for use of chemicals. WeLASER technique is a novel technique of weed control developed under the HORIZON 2020 project WeLASER which objective is to reduce the use of herbicides while improving productivity and competitiveness. The WeLASER weeder is an autonomous mobile robot using high-power laser to eliminate weeds. It is a complex solution using autonomous systems, artificial intelligence (AI), and advanced geo-positioning. The invention is developed, integrated, and tested in the project "Sustainable Weed Management In Agriculture With Laser-based Autonomous Tools - WeLASER".

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 the Technology Readiness Level 7 (TRL 7). To be commercialized, the product must attain in further development Technology Readiness Level 9 (TRL 9). The commercialization product will be equipped with four high-power lasers. The WeLASER machine has four baseline components 1. 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.

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

The knowledge about perceptions of farmers towards technological innovations is important for agricultural machinery stakeholders, for research centers, and for policymakers [31].

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

## 2. Materials and Methods

### *2.1. Statistical Approach*

The overall goal of the survey is to provide the insight on the attitudes toward the innovative (laser) weed control tool (device - autonomous robot) being the subject of the study, to get knowledge whether farmers see an opportunity or not to implement it and what are the barriers and possibilities of implementing the device in practice. The intention was to get valuable insight regarding future implementation of precision agriculture techniques in weed control. Research questions of the study are as follows:

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- What are the experiences and attitudes of farmers towards innovative farming tools based on automation, advanced electronics, communication and artificial intelligence?
- What could be the barriers and opportunities of implementing WeLASER device in practice?
- How would current experiences vs expectations of farmers related to implementation of innovative technologies influence their attitude towards WeLASER implementation?

According to the Diffusion of Innovation (DOI) E.M. Rogers theory [32,33], adoption means that a person does something differently than what they had 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 that is expressed by evaluating a particular entity with some 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 integral part of Theory of reasoned Action (TRA), its modification – the Technology Acceptance Model (TAM), and the Theory of Planned Behavior. These theories/model includes "attitudes" in its core.

Attitudes are understood as predicting intentions and assume a rational ('reasoned', or 'planned') process [34–37]. An attitude can be defined as an evaluative judgement, either favorable or unfavorable, that an individual possesses and directs towards some attitude object. In the context of technology, the attitude towards technology is one's positive or negative evaluation towards the introduction of new kinds of technology in given environment [32,33,38]. The conceptual framework is presented in **Error! Reference source not found.**.

**Table 1.** Conceptual framework – factors related to 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 using [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 a preexisting needs in the farming systems<br>*6. Are you satisfied with the available weeding solutions in your work?* | [42] |

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| | | | |
|---|---|---|---|
| P7 | Attitude towards using/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 using/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] |

The concept of assessment is presented in figure below (**Error! Reference source not found.**).

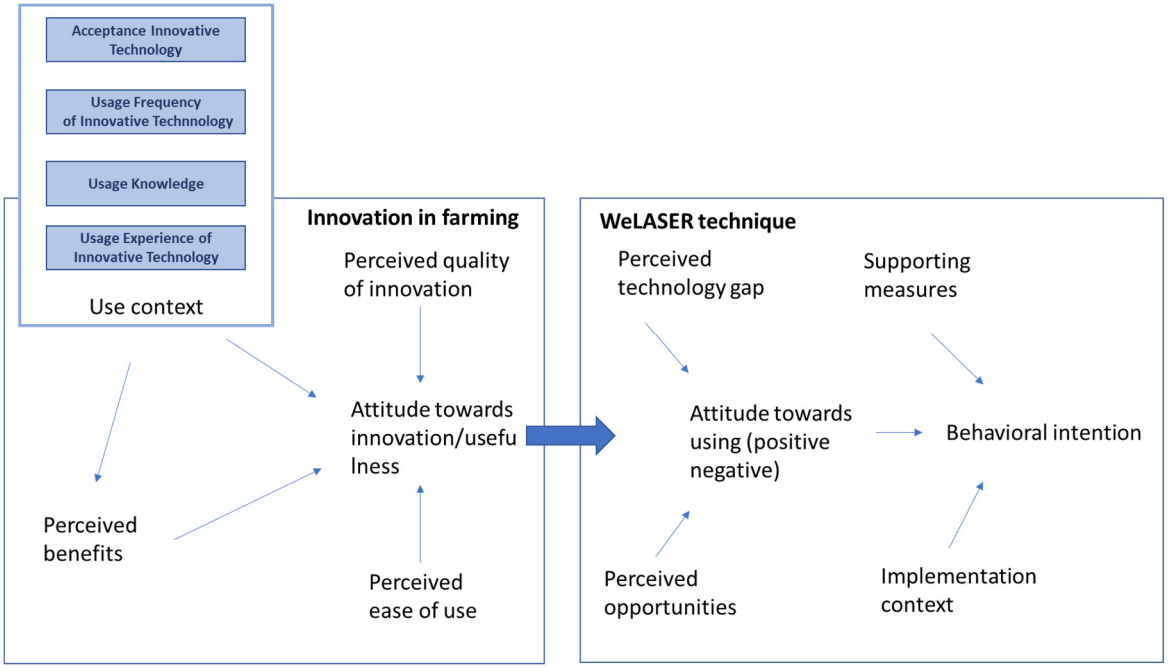


**Figure 1.** General concept of assessment.

*2.2. CATI Survey*

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

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transformation take place slower. Based on the adopted goal of the CATI survey, assumptions regarding the analysis and the number of cross-sections through which we will analyze the results of the survey were defined. Assumptions (sample selection criteria) we adopted for the survey are as follows:

- farmers are engaged in production crops, vegetables, horticulture
- cross section for the farms of the surface over 1ha: 50% of farms from 1-49ha and 50% for farms over 50+ha.
- farmers have made modernization investments on their farms in the last 10 years.

For these parameters a sample of at least N=30 could be obtained both for large and medium as well small sized farms in each country: Denmark, Poland and Spain. According to the statistical rules if the sample size is greater than 30, then we could use the z-test where the test-statistic follows a normal distribution. In addition to these sample selection criteria other parameters including: type of farm, age/gender of the manager, level of education will be obtained randomly, which can also allow to perform cross-sectional analysis depending on the results. The sample N=100 was planned as it has a wide margin to obtain results which allow to carry out cross-sectional analysis (farm scale) sufficient, from the point of view of the CATI survey goal. The table below presents the number of agricultural holdings in the three analyzed countries: Denmark, Spain and Poland.

| Country | Number of agricultural holdings | | |
|---|---|---|---|
| | from 0 to 49,9 ha | 50 ha and more | Total |
| Denmark | 24110 | 13260 | 37370 |
| Spain | 842530 | 101780 | 944310 |
| Poland | 1390040 | 31520 | 1421560 |

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

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

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

With sample $n$ = 97 the assumptions made above are fulfilled for farms from 0 to 49,9 ha and from 50 ha and more. Thus, a sample size of $n$ = 100 is sufficient for carrying out quantitative statistical analysis (for this $n$ the margin of error $E$ = 0.098).

According to the conceptual framework, the questionnaire was developed with three parts:

- respondent profile;
- section on perceiving innovation in agriculture based on farmer's own experiences or his views
- section on evaluation of WeLASER implementation from the individual perspective of a farmer.

## 3. Results

A total of 300 participants took part in the survey, 100 each from Denmark, Poland and Spain. Respondents had to answer 9 questions about themselves and 13 questions about their opinions. Questions describing the respondents and their farms are presented 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 |
| S5 | What is the type of cultivation system on your farm? |
| S6 | How old are you? |
| A2 | Age of farmer expressed in 3 classes |

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| | |
|---|---|
| S7 | Gender: |
| S8 | What is your highest education level? |
| S9 | What level of agricultural education you have? |

Responses to the above questions were expressed on a nominal scale, with the exception of responses to questions on age and farm size. However, in further analyses, data on age and farm size were expressed in three classes. Below is a list of key questions describing respondents' opinions related to the introduction of the new laser weed removal tool. There were also additional questions describing alternative preferences, such as "What comes second or third most important to you?".

| 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? |

### *3.1. Statistical Approach*

Within the frames of the WeLASER project surveys involving 100 respondents in 3 countries were conducted. Because data obtained were mainly nominal, in the elaboration of the obtained results, cross tabulation analysis was used. 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 formula (2):

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

where $O$ are observed values, $E$ are expected values and $i$ denotes row index, $j$ denotes column index of the table. Test statistic from the formula above is approximately distributed as $\chi^2$ with ($r$ - 1) x ($c$ - 1) degrees of freedom where $r$ is the number of rows, $c$ is the number of column. The p-value was calculated based on $\chi^2$ distribution value. The p-value defines probability that the Null hypothesis $H_0$ for given pair of variables is true. If the p-value is small enough we reject the Null hypothesis, if *p-value* is high the null hypothesis is not rejected. The $\alpha = 0{,}05$ was taken as significance threshold. The test for independence may be expressed as follow:

$H_0$: R and C are independent; no relation between R and C; Oi = Ei,

$H_1$: R and C are dependent; relation exist between C and R; Oi ≠ Ei,

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where: R represent row, dependent variables, C represent columns, independent variables, $H_0$ denotes null hypothesis, $H_1$ denotes alternative hypothesis, the notion Oi refers to observed values in cross table and Ei refers to expected values in cross table.

Besides p-value, the upper bound for the Bayes factor $\bar{B}$ and was calculated (3). This is calculated for a given *p-value*, maximum coefficient indicating how many times the alternative hypothesis $H_1$ is more true than the null hypothesis $H_0$. The upper bound for the Bayes factor $\bar{B}$ and was calculated by formula [46,47]:

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

In calculation of the strength of the association between two crosstab variables Cramer's V was used [48]. It is defined by the following formula (4):

$$V = \sqrt{\frac{\chi^2}{n \times t}} \quad (4)$$

Where $t$ is calculated according following formula (5):

$$t = minimum\ (r - 1, c - 1) \quad (5)$$

where $t$ smaller result of the two subtraction and $n$ is the number of respondents.

In interpretation of Cramer's V coefficient Lee scale was used [49]. Lee proposes following thresholds for interpretation of 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 |

Additionally z-test and p-value were calculated for comparisons of column proportions. The z-test value is calculated according the formula (6) [50]:

$$Z = \frac{dif}{SE_0} \quad (6)$$

where numerator $dif$ constitute difference between column proportions and is calculated according the formula (7):

$$dif = p_a - p_b \quad (7)$$

where $p_a$ is the first proportion of given row in 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 according following formula (8):

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

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

$$\hat{p} = \frac{p_a \cdot n_a + p_b \cdot n_b}{n_a + n_b} \quad (9)$$

Under null hypothesis both columns proportions have the same value and it is equal $\hat{p}$. After calculation of z-test, and assuming that it follows standard normal distribution our p-value is calculated as 2-tailed significance using formula (10):

$$p - value = 2 \cdot \Phi(Z) \quad (10)$$

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

Calculation of The Pearson chi-square statistic and Cramer's V association coefficient were conducted with application of GNU PSPP software [51], which is a free alternative for IBM SPSS Statistics package. Z-tests pertaining the difference in column proportions were calculated using MS EXCEL.

In 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 analyzed in the survey. A total of 110 pairs of relationships were examined. The analyses were conducted separately for Denmark, Poland and Spain.

**Table 2.** 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 |

Analysis was divided into 2 stages. The first stage contains: (a) performing tests for existence of association by calculation of p-value of the Pearson chi-square statistic; (b) assessment of strength of the association with Cramer's V coefficient and (c) calculation of descriptive statistics of these two parameters. Comparison of this parameters for Denmark, Poland and Spain and selection data for further analysis at the second stage.

The second stage pertain analyses performed on selected dataset and contains: (a) comparisons of column proportions for Denmark, Poland and Spain for variables describing opinion of respondents; (b) examples of crosstabs calculation with significant association ($\alpha$ less than 0.05) and (c) analysis of crosstab results for dominant responses and crosstabs with p-value < 0.0005 (it represents the maximum value calculated by GNU PSPP software, which the program records as 0).

### *3.1. Results of Tests for Existence of Association and Calculation of Strength of the Association*

#### 3.1.1. Results for Denmark

The table below presents probability of not rejecting null-hypothesis ($H_0$) or rejecting the alternative hypothesis ($H_1$) for variables of Denmark. The p-values below 0.05 shown in bold red indicate dependence and the existence of a relationship (association), and the values above 0.05 shown in blue indicate independence and no relationship (or more precisely, no proven relationship / association).

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**Table 3.** Results of the test on independence of key variables describing respondent profile and respondent opinions for Denmark. Red bold - dependent variables, blue – independent variables.

| | 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 the Denmark, we have **46** pairs with *p-value* less than 0.05. Besides there are **36** cases with *p-value* less than 0.01 and **32** cases with *p-value* less than 0.005. There are **21** cases where the *p-value* calculation yielded 0 (in reality they are < 0.0005). We may conclude that in case of **42,2**% of analyzed pairs there is relation between variables (*p-value* <0.05). The median of p value is 0.096 and the estimator of variability, median absolute deviation about median (MAD) is 0.142.

The next table shows the strength of relations and presents results of Cramer's V calculation only for pairs of variables with p-value less than 0.05. Out of total **46** pairs meeting selection criterion, **17** (37.0%) scored at least 0.4 (relatively strong association). Minimum value of Cramer's V is 0.25. Median of Cramer's V association coefficient for 46 pairs is 0.36, and MAD is 0.074. The strongest associations are observed for the pairs P1-A1 (0.69), P9A-A2 (0.62) as well as P1-P5 and P8-P9A (0.58).

**Table 4.** Results of the Cramer's V association of key variables describing respondent profile and respondent opinions for Denmark. Orange – value below 0.4, at least 0.4 – red bold.

| | 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** | | | | | | | | | | |
| 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

### 3.1.1. Results for Poland

The table below presents probability of not rejecting null-hypothesis ($H_0$) for variables of Poland.

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**Table 5.** Results of the test on independence of key variables describing respondent profile and respondent opinions for Poland. Red bold - variables dependent, blue – independent variables.

| | 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 analysis, we have **25** pairs with *p-value* less than 0.05, **14** cases with *p-value* less than 0.01 and **9** pairs with *p-value* less than 0.005. There are **6** pairs where calculation of the *p-value* yielded 0. We may conclude that in case of 22.9 % pairs there is relation between variables (*p-value* <0.05). The median for p-values is 0.343 and the MAD is 0.436. The median for Poland is higher than for Denmark.

The next table presents results of Cramer's V calculation for pairs of variables of Poland with p-value less than 0.05. In total there are 22 pairs meeting this criterion. Three of them scored at least 0.4. Minimum value of Cramer's V is 0.24. Median of Cramer's V association coefficient for 22 pairs is 0.31 and MAD is 0.02. The three strongest association is observed for a pair P3-P9A (0.43), P9A-P12 (0.41) and P7-P12 (0.4). The median of Cramer's V for Poland is higher than for Denmark.

**Table 6.** Results of the Cramer's V association of key variables describing respondent profile and respondent opinions for Poland. Orange – value below 0.4, at least 0.4 – red bold.

| | 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

3.1.1. Results for Spain

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The table below presents probability of not rejecting null-hypothesis ($H_0$) for variables of Spain. In this case, we have **26** pairs with *p-value* less than 0.05, **12** cases with *p-value* less than 0.01 and **11** cases with *p-value* less than 0.005. There are **8** cases where the *p-value* calculation yielded 0. We may conclude that in case of **23.9**% of analyzed pairs there is relation between variables (*p-value* <0.05). The median of *p-value* is 0.256 and the MAD is 0.307. These values are higher than their counterparts for Denmark and lower than their counterparts for Poland.

**Table 7.** Results of the test on independence of key variables describing respondent profile and respondent opinions for Spain. Red bold - variables dependent, blue – independent.

| | 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 | | | | | | | | |
| 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 below shows results of Cramer's V calculation for pairs of variables with p-value < 0.05.

**Table 8.** Results of the Cramer's V association of key variables describing respondent profile and respondent opinions for Spain. Orange – value below 0.4, at least 0.4 – red bold.

| | 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. Minimum value of Cramer's V is 0.26. Median of Cramer's V association coefficient for 26 pairs is 0.31 and MAD is 0.052. The strongest association is observed for a pair P7-P12 (0.59). The second strongest is observed for the pair P9A-P12 (0.49) and the third is a pair P9B-S9 (0.45).

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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 table below shows the descriptive statistics of the *p-value* and Cramer's V association coefficient for analyzed countries. Statistics of Cramer's V only include pairs of p-value <0.05.

**Table 9.** 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

In most cases variables representing both *p-values* and Cramer's V association coefficient do not fit to normal distribution. For this reason, non-parametric estimators of location and dispersion (median, MAD) are better in comparison to classical estimators (arithmetic mean and standard deviation).

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

In case of Cramer's V coefficient we may see that 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 medians of Cramer's V between Denmark and the other two countries are statistically significant. The differences in medians of Cramer's V between Poland and Spain are minor and statistically not significant. Poland has the smallest Cramer's V association coefficient variability expressed in terms of standard deviation, while Denmark has the highest Cramer's V.

### *3.1. Comparisons of Column Proportions for Denmark, Poland and Spain*

This part of results pertain only for variables representing respondents' opinions. The results of column comparison proportions are presented in the table below. The frequencies of occurrence of differences with p-value < 0,1 and p-value < 0,05 were calculated and results are presented in table below.

**Table 10.** Results of column proportion comparison for Denmark, Poland and Spain.

| $\alpha$ | Denmark | | Poland | | Spain | | 3 states |
|---|---|---|---|---|---|---|---|
| | 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 |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total | 54 | 27.00 | 84 | 42.00 | 62 | 31.00 | 200 |

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

It may be observed that the total number of significant differences in column proportions is 200 and the number of differences with $\alpha$ less than 0.05 (101) is generally the same as with $\alpha$ less than 0.10 (99). In contrast to the results of previous parameters (p-value and Cramer's V) the highest number of significant differences pertains Poland and the lowest - Denmark. And this is also truth for total number of differences as well as for differences with both $\alpha$ levels.

**Examples of crosstabs with significant association ($\alpha$ less than 0.05)**

There are 9 common pairs for all 3 countries 5 of which have mean of Cramer's V greater than 0.4 (relatively strong association). These are **P9A-P12** (0.475), **P1-P5** (mean of Cramer's V is 0.423), **P7-P12** (mean is 0.420), **P7-P8** (mean is 0.415), and **P1-P2** (0.415). Others remaining pairs are P8-P12, P6-P7, P5-P7 and P1-P8.

For the sake of conciseness, only one pair of questions was chosen for a more detailed description and it is P1-P2. The crosstab is composed of the two questions: in columns P1 constitute independent variable. The P1 question is: "**Do you use innovation on your own farm?**", and possible answers are as follow: (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 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: (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 of each pair of answers for Denmark. The number of cases also represents the percentage, since we have exactly 100 cases in total.

**Table 11.** Crosstab for 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

In case of Denmark, the calculated p-value of the Pearson chi-square statistic is 0 (less than 0.0005) and Cramer's V coefficient is 0,56. From the table above, it can be inferred that 44% of respondents are already using innovations on their farms, and 40% are not using them, but are interested in them. It can be concluded that those who use innovations it is no problem to implement innovative technologies on their own (12 cases and all answers A in group "i"). It may be observed that there is significant difference in column proportions for the group of row "ii" between columns A and C. The p-value of z-test is less than 0.05 and means that proportion of A answers is significantly higher than proportion of C answer. The reverse result is observed for the row "iii" where proportion of C is significantly higher than proportion A.

In the next contingency table pair of answers for Poland are presented.

**Table 12.** Crosstab for 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 |

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| | A | B | C | D | Total |
|---|---|---|---|---|---|
| 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

In case of Poland, the calculated p-value of the Pearson chi-square statistic is 0 and Cramer's V coefficient is 0,37. We may observe that nobody gave answer "Hard to say" on the question P1, thus the column E is omitted. We may inferred from the table for Poland that 64% of respondents already use innovations on their farms.

For 51% of all cases it is not a problem to implement innovative technologies even though it requires to acquire new skills and knowledge. In this group of respondents (answer "ii") we observe significant differences in column proportions. Proportions of column A are significantly higher than proportion of column B, C and D. But only difference between proportions of columns A and D are significant with $\alpha$ equal 0.05. For remaining two differences (marked with orange italic fonts) the significant level $\alpha$ was 0.10.

Next contingency table presents pair of answers for Spain

**Table 13.** Crosstab for 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

In this case, the calculated p-value of the Pearson chi-square statistic is 0.021 and Cramer's V coefficient is 0,27. We may observe that 70% of respondents already use innovations on their farms. About half of them see no big deal in implementing innovations while other half see problems and necessity to rely on external support. In case of Spain the group of respondents who see a problem in implementing innovative technologies is the most numerous (30% of all respondents). In this group (represented by row "iv") proportion of column of those who already use innovations significantly surpasses proportion of column of those who do use innovations (columns C and D). Though there are slight variations in significant level of the difference in column proportions between A and C and between A and D. The first comply to $\alpha$ equal 0.05 while the second to $\alpha$ equal 0.10.

### *3.1. The Dominant Responses in Selected Crosstabs for Variables Describing Opinions of Respondents*

In this part of the analysis, we looked at individual cross-tabulations. We chose crosstabs with a p-value of the $\chi 2$ statistic less than 0.0005. With this p-value, the alternative hypothesis H1 is at most 96.8 times more likely than the null hypothesis H0.

A total of 27 cross-tabulations fit the above criterion, 13 from Danish cross-tabulations, 6 from Polish cross-tabulations and 8 from Spanish cross-tabulations. Each crosstab consists of r × c intersections (number of rows times number of columns) representing answer pairs. Dominant intersections that is, dominant pairs of responses are described below.

Denmark

Denmark's first cross-tabulation with a p-value of 0 is the P1-P2 cross-tabulation consisting of 25 intersections. We can see that the dominant group accounting for 29% are respondents who already use innovation on their farm and think it is easy to implement innovative technologies on their own.

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In the next crosstab - P1-P3 consisting of 20 intersections the dominant group accounting for 42% are respondents who already use innovation on their farm and think that innovative technologies are usually of good quality and reliable.

In case of P1-P5 crosstab (30 intersections), dominant group accounting for 27% are respondents who already use innovation on their farms and believe that implementing new technologies brings essential economic gains (reduce costs, higher income).

The results of the P1-P6 cross-tabulation (25 intersections) indicate that the dominant group accounting for 31% of the number of respondents is already applying innovations on their farms and is rather satisfied with the weed control solutions available.

For cross-tabulation P1-P8 (25 intersections), the dominant group accounting for 27% are respondents who do not use the innovation on their farms, but are interested in using it and would be willing to implement the WeLASER weed control technology, but believe it only partially solves their weed control problems.

The P1-P12 cross-tabulation (25 intersections) shows that the predominant group, which represents 29%, are farmers who are already using the innovation on their farms and are very willing to follow the further development of WeLASER weed control technology as a potential future application on their farm.

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

Cross-tabulation P2-P5 (30 intersections) is dominated by the 20% of respondents who believe that the implementation of innovative technologies requires the acquisition of new skills and knowledge, but this is rather easy to manage, they also believe that the implementation of innovative technologies brings significant economic benefits (cost reduction, higher income).

Crosstab P3-P5 (24 intersections) shows that 34% of respondents (the dominant group) rate innovative technologies as usually of good quality and reliable, and that these technologies bring significant economic benefits.

In cross-tabulation P5-P6 (30 intersections), the predominant group of respondents accounting for 35% are those who believe that innovative technologies have significant economic benefits, while they are unlikely to be satisfied with the weed control solutions available.

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, while also believing that they are likely to follow further development of WeLASER weed control technology as a potential future application on their farm.

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

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

Poland

The first crosstab for Poland with a p-value of 0 is the P1-P2 cross-tabulation consist of 20 intersections. We can see that the dominant group accounting for 34% are respondents who are already applying innovations on their farm and believe that it is easy to implement innovative technologies on their own.

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

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

Crosstab 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 feels that WeLASER appears to be a good solution and is likely to follow further development of the technology.

The last cross-tabulation for Poland P8-P10 (30 intersections) shows that 23% of respondents (the dominant group) are rather interested in implementing WeLASER weed control technology, even if it does not solve all weed problems, and 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 P1-P5 crosstab consisting of 35 intersections. The dominant group representing 37% are respondents who already use innovation on their farm and consider that the most important benefit of implementing innovative technologies is the improvement of working conditions.

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

In cross-tabulation P3-P5 (28 intersections), 37% of respondents (the dominant group) believe that innovative technologies (machines and specific tools) available on the market are usually of good quality and reliable, and that the most important significant benefit of implementing 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 the agricultural land (subdivided plots) and they strongly considered this technology useful for weed control (they are interested in implementing 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 in their work and for them the WeLASER weed control technology seems to be a good solution.

From cross-tabulation P7-P8 (25 intersections), we can learn that for the dominant group accounting for 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 implementing WeLASER weed control technology on their farm.

In the P7-P12 cross-tabulation (25 intersections) the dominant group accounting for 43% of respondents, reckon that the WeLASER weed control technology seems to be a good solution and 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 accounting for 40% of respondents would definitely find the technology useful in weed control and are interested in implementing WeLASER weed control technology on their farm and will definitely follow the further development of WeLASER.

## 4. Discussion

The results obtained show reasonable patterns related to the three groups of questions: respondents profiles, experience and attitudes towards innovation in agriculture and attitude towards WeLASER within the regional context. There are essential differences between countries.

**Denmark**

It is observed that innovation in Denmark is implemented by well-established farmers usually of higher education. Usage of innovation is associated strongly to farm size with prevalence to large

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farms and to a lesser degree to farmers' age. Use of innovation was declared mostly by middle age farmers and farmers of high education level - 43% of respondents **already** using the innovation and 7% of those considering innovation.

Based on the results it can be underlined that the farms' size determines the experience and the socio-economic potential of innovative techniques adoption. According to Danish farmers' perception the essential factors is the easiness of use of these technologies, their quality and potential benefits to them. These attributes are strongly associated with the farms' size except for the perception of benefits. 12% of farmers using innovation perceive it as easy to use, and 29% declare that even if new technology requires new skills it is not a problem to learn. For 40% of all respondents it is also relevant answer and 27 % declare that additional assistance is required. It can be interpreted that advanced agriculture in well-established farms managed by experienced practitioners form conditions for innovation adoption. Farmers experienced in using innovation see at the same time essential benefits in its implementation - around 44% of those who already use of innovation (for all respondents 31%), 8 % those who consider using it and 40% those who are interested in using it (all respondents 45%).. Working conditions and economic gains were pointed out as the main benefits. This agrees with studies in United States, where the key factors of PA adoption is farm size, computer literacy, full time farming, farm type and farm location [52].

Among Danish respondents there is observed high level of satisfaction from using weed control solutions (rather satisfied - 46%), although the prevailing answer suggests some uncertainty. Farmers' views on weed control measures are strongly associated with the current experience of using innovation in general, positive assessment of innovation reliability and quality and also with perception of its benefits. Farmers who are rather satisfied with the weed control solutions at their farms view the benefits of innovative techniques in terms of improvement of working conditions 17% and essential economic gains 35%. These respondents perceive the innovative techniques as usually of good quality and reliable 68% (42% of all respondents). It suggests that the quality expectations of farmers are rather high and demanding towards the weeding techniques as well.

In Denmark's data the association between innovation use at the farms and opinion on potential WeLASER use is rather weak or there is no relevant association observed. For example the perception of good quality of innovation is not associated with the willingness to adopt WeLASER. These farmers in the majority do not perceive WeLASER to be an important technique for their farms (probably be or decisively not useful on their farm 39.4% answers). Only 11% expressed the view that they might rather implement the technique, although it will not solve all the problems with weeds. It can be explained that various agricultural practices, economic and structural conditions determine their perception. Moreover, the high satisfaction level of current practices does not stimulate them for looking into more radical solutions.

Although, farmers assess positively WeLASER technology in principle, there is observed a restraint in formulating their opinions on its adoption 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 a good solution. The majority of these farmers expressed interest in implementation of WeLASER but they see it as a partial solution to weeding problems (90% of all respondents). The restraint toward the technology may be explained also that there are not many applications of the robot today tested in practice, although the curiosity and expectations among the farmers are visible. Among respondents who do not use innovation 24 % are both interested in innovation in general and see a potential for WeLASER implementation. The uncertainty is also visible in strong association between responses on the satisfaction of using current weeding control solution - "as rather satisfied" and using WeLASER -"rather WeLASER can solve partially problems". The general restraint is the most probably related to the lack of specific information as 82% of Danish respondents express the need for mor reliable and accurate information on the technology for eventual its implementation. It agrees with other studies where the factor of performance expectancy should be enhanced by better communication [43].

The farmers evaluating WeLASER as a suitable solution for their farms indicated renting of services (35%) as the way of adoption, purchase with external funding (25%), joint purchase (15%)

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and renting without service (10%). Potential interest (probable) in further developments of WeLASER was expressed by young and middle age farmers alike.

**Poland**

Predominantly, middle age farmers use innovation in farming operations but regarding the farms' size there is an even distribution between small, medium and large farms without strong indication. This can be explained by the high share of medium size farms (up to 49 ha). This agrees partially with other studies in Poland where it was observed that precision agriculture technology is more popular among farmers who are less than 40 years old, who have higher education and big agricultural farms [53,54].

In Poland the scale of farming and using of innovation were also identified as essential factors of perception of innovation adoption. There is a statistical association between farms' size and the perception of the easiness of use. 51 % respondents perceive the technologies as requiring additional skills and knowledge and declare at the same time that it is not a problem for them to learn. In this group 60% farmers are operating small farms. Moreover, 21% of all respondents can implement the technology by themselves. In these both groups there is seen a prevalence to higher level of education. This indicated that there is no specific barrier related to the easiness of technology implementation related to knowledge and experience of the farmers, there is general openness towards new technologies. Nevertheless, these results indicate that strengthening knowledge transfer and education should be promoted in Poland especially among small holders as well as development of appropriate advise services.

Quality of the innovative technology is also an essential factor for Polish farmers. Farmers already using innovation assessed it as "usually of good quality" - 51% of respondents. For all respondents it is 72% against 15% expressing the view that they are "usually of bad quality". Positive perception of quality of innovative techniques is also associated with the level of satisfaction of weed control applied in farms. The share of the answers that "they are of good quality" and that the "weed control measures are satisfactory" is 50%, For all respondents the share is 72%. It can be interpreted as a general positive experience and attitude toward innovation and this opinion regards also weeding practices.

Perception of WeLASER as a good solution is related in strong terms to perception of innovative technologies key feature: quality, easiness of use, benefits, and satisfaction of weeding. It is also associated with willingness to implement this technique but previous positive experiences with the innovation does not influence much the willingness to adoption of WeLASER. The discrepancy can be explained that there are might be an essential limitations of the robot use. For example respondents who perceive WeLASER as a good solution and potentially would implement this technique as technology only "partially solving weeding problems" is 35% (48% all respondents). At the same time respondents who would implement the robot as a partial measure are mostly satisfied with currently applied weed control 33% (48% for all). On the contrary 34 % do not see definitely or probably the reason for implementation of the technique in their farms.

Perception of good quality of WeLASER and willingness to its implementation is also related to willingness to follow further developments of WeLASER project and to strong opinion about the key factors for implementation. Most of the respondents (46%) indicated public support as the main factor and 31% indicated more stringent policies. The public support was especially pointed out by smaller holders. It also confirms that WeLASER technology can be adopted by farmers having better financial standing and more favorable conditions and opportunities for adoption.

There is uncertainty related to WeLASER adoption as the perception of WeLASER technique suitability would require developing of new skills (33% of all respondents). The perception of the suitability (WeLASER as partial solution) with 58.8% of those perceiving positively WeLASER indicate on one hand essential potential as well as existence of barriers of application.

Among the farm's attributes of innovative technology implementation, financial condition of the farms was indicated by the farmers (45% of all respondents) as the most important. This opinion was expressed especially by the middle aged and young farmers. Reliable and accurate information on

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technology performance, including costs and benefits for specific crops was pointed out by 57% of all respondents.

**Spain**

According to Spanish farmers who are already using innovation, quality and perception of benefits seems to be strong factors of implementation. 79% of all respondents answered that innovative techniques are usually of good quality and always of good quality for 15%. In the first category of responses 37% indicated improvement of working conditions as the main benefit (for all respondents it is 46%) and increase of productivity 14%. The second benefit indicated by them is the increase of productivity. Regarding the easiness of innovation there is a distinct split between two groups perceiving the innovation as "requiring new skills, but being not problematic" (25% all respondents) and those who "require external support and advise" (30%).

Acceptance of WeLASER technique as good solution is high. It is visible in case of respondents already using innovation - for 55% of respondents it is potentially good solution and for 11% it is "a definitely good solution". For all respondents it is 72 and 17% respectively. At the same time 38% of respondents using the innovation find WeLASER technology as definitely useful in weed control 38% (46% of all respondents) and 17% see it as solution which rather solve only partially weeding problem (21% of all).

In Spain there is observed a strong association between expressed dissatisfaction of weeding practice with positive evaluation of WeLASER and willingness to its adoption. Most of the farmers expressing their interest in implementation of WeLASER are rather not satisfied with weed control - 17% or rather satisfied - 26%. In case of respondents for whom WeLASER can only partially solve their problems, it was 6% and 12 % respectively. At the same time for the respondents who are not or rather satisfied with currently applied weed control solutions, WeLASER seems a good solution 66% and as definitely good solution 15%. The potential adopters declare at the same time use of innovation, see importance of the farms specific conditions, and see essential benefits. These results are rather unique among the researched countries showing a strong need for new solutions.

Another unique feature is that Spanish farmers who expressed positive attitude towards implementation of WeLASER (81.2% of all) indicated as the potential main barrier the structure of the land (dissected plots). Only 15.4% indicated financial condition as the main factor. There is visible a high expectation of the farmers as most of them are willing to follow up further development of WeLASER technique.

**Country comparison**

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

Other studies point out farm size but also farming system (organic/conventional), and occupational structure (part-time/full-time) as relevant attributes influencing the evaluation of advantages and disadvantages of field crop robots [28,55,56]. It also agrees with the conclusion regarding Denmark on the well-established farms in terms of economic standing and experience being the most innovative.

Although, the current experiences with innovative solutions are positive in all surveyed countries, application of WeLASER pose a challenge as the expectations regarding quality are high.

In Denmark as the country of most experienced farmers in the precision agriculture the responses to the questions were more consistent than in other countries which can be interpreted as a result of higher experience of using the innovative solutions than in Poland and Spain. It should be stressed that Danish farmers were more skeptical and expecting reliable proof of WeLASER performance. In a German case study there is also shown a moderate impact of previous experience on further advancements [42].

The results suggests that in Poland and Denmark farmers were more confident in adopting new techniques on their own or through development of new skills than in Spain where there was

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expressed stronger the need for external advise and support. From that perspective it has to be promoted as pointed by other studies [57] a holistic service into areas with low precision agriculture (PA) adoption. In this regards in studies in US there are identified barriers related to deliver precision agricultural services; equipment, costs reducing precision services profitable [58]. It should be also recommended to provide simple operational procedures to support the shift towards precision agriculture solutions [19] and strengthen the education of farmers, especially for smaller farms holders [17,59].

It has to be underlined that the farmers in all surveyed countries pointed out at social aspects (working condition) and to a lesser degree at economic aspects (increased profitability) as the key benefits of using innovation in agriculture. It disagrees with other studies pointing out at the economic factors [60] but other studies [42,43] also points out at the reduced workload as important factor. Environmental aspect was perceived as of the least importance, although various studies points out many benefits related to precision agriculture [61,62]. It might be reflected in respondents perception of the legal requirements regarding herbicides use. The economic feasibility of the technology, national policies and the legal situation resulting from these policies are mentioned also in other studies [42]. It is viewed [63] that policy inducements could change the relative input/output prices faced by farmers stimulated the adoption.

Results from all countries suggests that WeLASER technique can be used mostly as a complementary solution and not as a stand-alone technique as most of the respondents indicated that WeLASER can solve only partially their weeding problems. Moreover, as other studies points out there should be involved other PA techniques enhancing effectiveness of weeding [64]. It should be further noted that the innovative techniques might not be relevant in all farms depending on specific conditions [65].

In all countries there is seen a restraint towards adopting the technology as it is quite a novelty and there are many aspects that should be resolved before commercialization and practical use. It agrees with the strong notion that for farmers to adopt a technology, it must first meet their needs. It is observed in other studies that most of farm innovations were conceived on-farm and then commercialized by companies [66]. At the same time the results point out at openness towards the WeLASER technology. Spanish farmers see it the most as a potential technique for solving their weeding problems.

There is seen a distinct group in each country of potential adopters characterized by consistency in the answers related to the quality of WeLASER, its suitability (partial) and willingness to follow up further developments. Similarly, a very positive approach towards the innovation process was also observed [67] in user groups, who have already oriented themselves and adapted all factors of production to the innovative change.

There is important differences in opinions related to the business models of implementation. In Spain prevailed opinion on renting of weeding technology, in Poland purchasing with non-refundable grants, in Denmark, renting of services and also joint purchase and purchase with external funding. Non-purchase options such as contractor services and machinery sharing were identified as the preferred modes of robot deployment in Bavaria, Germany [28].

Public support was pointed out in all countries as important factor of implementing WeLASER in Denmark 45%, Poland 46%, Spain (41%) but in Denmark and Spain there were also other answers important labor market conditions and food quality. In Poland 31% indicated also agricultural and policy requirements. It is in line with recommendation of European policy on delivering tools and incentives especially for small and medium size farms to facilitate adoption of innovative technologies [68–70].

In all countries farmers pointed out that they need the reliable and accurate information on the technology performance and costs and benefits of its usage in practices (Denmark 82% of respondents, Poland 57%, Spain 36%). This is underlined also in other studies. Robot suppliers should better inform farmers about the performance of their products, for instance by involving farmers in the development process of the robots [42] and through demonstration of the key benefits in practice [71]. According to other studies the information has to be provided by the robots producers/dealers

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[42] as well as by the institutions responsible for advising farmers in their practices [72]. Adopting new technology is a process that starts with farmers knowing that it exists and then forming favorable opinions that lead to adoption and then based on results of their research, form an intention to try it [1]. The opportunity and experience of use PA technologies on the plots of a fellow farmer is increasing the likelihood to adopt these technologies [73]. The role of positive impact of advisory on adoption rate was observed in study in US [55]. The need for improved information, financial support mechanisms including more accessible subsidies, and service provision, as well as, reliable implementation and aftercare support was also indicated as important factors of adoption in less advanced regions and countries [74].

## 5. Conclusions

In the study there were identified key aspects of implementation of laser based weeding technology form the farmers perspective. Farmers in three countries were questioned using CATI method. The results were analyzed using statistical methods to: 1) determine the relation (probability of association) between the respondents profile, the perception of innovation and attitude to WeLASER implementation in their farming practice.

There are seen patterns in the responses indicating that there are groups of potential adopters in all countries who perceive positively the innovative technique and formulate expectations towards WeLASER. According to the results the highest potential is in larges farms operating by young and middle age farmers. It agrees with other studies concerning adoption of new technologies [75]. In Spain and Poland also holders of small farms see the reason of implementation. There are not observed many early adopters in the studied samples.

In all countries there is observed high confidence in potential implementation of WeLASER technique as high rate of farmers for whom application of the technology potentially will not be a problem and who can learn operations on their own. Nevertheless, there is, especially in Spain the need for supporting services and advice. It is advised to provide a good assistance and service for the users.

In future development of the technique there should be considered high quality of the technique meeting the expectations of the farmers. It can be also suggested that the functionality of the technique might be extended as it is viewed as partially solving problems of the farmers.

Implementation of the laser based weeder should be supported by means of providing funds but also by facilitating other forms of usage (leasing, renting, sharing).

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## References

1. Communication A Farm to Fork Strategy (COM (2020) 381 final). Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:ea0f9f73-9ab2-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF (accessed on 9.12.2023).
2. Petrova Beluhova-Uzunova R.; Dunchev D.M. Precision farming – concepts and perspectives. *Problems of Agricultural Economics* **2019**, *3(360)*, 142-155.
3. Communication The European Green Deal (COM (2019) 640 final). Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF (accessed on 9.12.2023).
4. Communication EU Biodiversity Strategy for 2030 (COM (2020) 380 final). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380 (accessed on 9.12.2023).
5. Communication EU A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040 (COM(2021) 345 final). Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:6c924246-da52-11eb-895a-01aa75ed71a1.0003.02/DOC_1&format=PDF (accessed on 9.12.2023).
6. Ekielski, A.; Wesołowski, K. Systemy agrotroniczne, **2019**, Toruń, Polska Izba Gospodarcza Maszyn i Urządzeń rolniczych, ISBN: 9788395509605
7. Pierce, F. J.; Nowak, P. Aspects of Precision Agriculture. Editor(s): Donald L. Sparks, Advances in Agronomy, *Academic Press*, **1999**, *67*, pp. 1-85. https://doi.org/10.1016/S0065-2113(08)60513-1.
8. Aubert, B.A.; Schroeder, A.; Grimaudo, J. IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology, *Decis. Support Syst.*, **2012**, 54, 510–520. https://doi.org/10.1016/j.dss.2012.07.002.
9. Long, TB.; Blok, V.; Coninx, I. **Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe : evidence from the Netherlands, France, Switzerland and Italy.** *Journal of Cleaner Production* 2016, *112*, 9-21.
10. Cortinas, E.; Emmi, L.; Gonzalez-de-Santos, P. Crop Identification and Growth Stage Determination for Autonomous Navigation of Agricultural Robots. *Agronomy* **2023**, *13*, p. 2873. https://doi.org/10.3390/agronomy13122873
11. Gonzalez-de-Santos, P.; Fernández, R.; Sepúlveda, D.; Navas, E.; Emmi, L.; Armada, M. Field Robots for Intelligent Farms—Inhering Features from Industry. *Agronomy* **2020**, *10*, 1638. https://doi.org/10.3390/agronomy10111638
12. Emmi, L.; Herrera-Diaz, J.; Gonzalez-de-Santos, P. Toward Autonomous Mobile Robot Navigation in Early-Stage Crop Growth. In: *Proceedings of the 19th International Conference on Informatics in Control, Automation and Robotics (ICINCO)* 2022. Lisbon, Portugal, 14–16 July 2022, pp. 411-41. https://doi.org/10.5220/001126560000327
13. Emmi, L.; Fernández, R.; Gonzalez-de-Santos, P.; Francia, M.; Golfarelli, M.; Vitali, G.; Sandmann, H.; Hustedt, M.; Wollweber, M. Exploiting the Internet Resources for Autonomous Robots in Agriculture. **2023**, *Agriculture* 13, 1005. https://doi.org/10.3390/agriculture13051005.
14. Emmi, L.; Fernández, R.; Gonzalez-de-Santos, P. An Efficient Guiding Manager for Ground Mobile Robots in Agriculture. **2024**, *Robotics*, 13, 6. https://doi.org/10.3390/robotics13010006.
15. Walczak, J.; Pomianek, B.; Ekielski, A.; Skudlarski, J.; Zeyland, J.; Hryhorowicz, M. Precyzyjne i inteligentne rolnictwo – stan i perspektywy wdrażania. Eds. Ekielski, A; Walczak, J. **2023**, Wydawnictwo Naukowe SCHOLAR
16. Boehlje, M.; Langemeier M. The Role of Information in Today's Uncertain Business Climate. farmdoc daily (11):41, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, March 18, 2021.
17. European Parliament, Directorate-General for Parliamentary Research Services, Daheim, C., Poppe, K., Schrijver, R., *Precision agriculture and the future of farming in Europe – Scientific foresight study*, European Parliament, 2016, https://data.europa.eu/doi/10.2861/020809
18. Gebbers, R.; Adamchuk, V. I.; Precision Agriculture and Food Security. *Science* **2010**, *327*, pp. 828-831. https://www.science.org/doi/abs/10.1126/science.1183899
19. Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing. Regulation (EEC) No 2092/91. Official Journal of the European Union L 189/2, 20.07.2007.
20. Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides, OJ L 309, 24.11.2009, pp. 71-86.
21. EC (2021) Organic production and products. European Commission. Available online: https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-production-and-products_en (accessed 9.12.2023).
22. Report from The Commission to The European Parliament and The Council On the experience gained by Member States on the implementation of national targets established in their National Action Plans and on

progress in the implementation of Directive 2009/128/EC on the sustainable use of pesticides. COM(2020) 204 final. Available online: https://food.ec.europa.eu/system/files/2020-05/pesticides_sud_report-act_2020_en.pdf (accessed on 9.12.2023).

23. Botta, A.; Cavallone, P.; Baglieri, L.; Colucci, G.; Tagliavini, L.; Quaglia, G. A. Review of Robots, Perception, and Tasks in Precision Agriculture. *Appl. Mech.* **2022**, *3*, pp. 830-854. https://doi.org/10.3390/applmech3030049
24. Cannon, N.; Melander, B.; Ståhl, P.; Kuebler, K.; Murdoch, A.; McCollough, M.R.; Beuling, D. J. A vision for the opportunities for precision non-chemical weed management in 2050 and beyond, EIP-AGRI Focus Group, 2019. Available online: https://ec.europa.eu/eip/agriculture/sites/default/files/fg_32_precision_farming.pdf (accessed on 9.12.2023).
25. Melander, B.; Munier-Jolain, N.; Charles, R.; Wirth, J.; Schwarz, J.; Van Der Weide, R.; Bonin, L.; Jensen, P.K.; Kudsk, P. European Perspectives on the Adoption of Nonchemical Weed Management in Reduced-Tillage Systems for Arable Crops. **2013** *Weed Technol.*, 27, pp. 231–240.
26. Gerhards, R.; Kollenda, B.; Machleb, J.; Moller, K.; Butz, A.; Reiser, D.; Griegentrog, H.W. Camera-Guided Weed Hoeing in Winter Cereals with Narrow Row Distance. 2020 *Gesunde Pflanz.*, 72, pp. 403–411.
27. Westwood, J. H., Charudattan, R., Duke, S. O., Fennimore, S. A., Marrone, P., Slaughter, D. C., Swanton, C., & Zollinger, R. (2018). Weed Management in 2050: Perspectives on the future of Weed Science. *Weed Science*, *66*(3), 275–285. https://doi.org/10.1017/wsc.2017.78.
28. Spykman, O., Gabriel, A., Ptacek, M., & Gandorfer, M. (2021). Farmers' perspectives on field crop robots—Evidence from Bavaria, Germany. *Computers and Electronics in Agriculture, 186*, 106176. https://doi.org/10.1016/j.compag.2021.106176
29. Lowenberg-DeBoer J., Huang I. Y., Grigoriadis V., Blackmore S., Economics of robots and automation in field crop production Precision Agriculture (2020) 21:278–299 https://doi.org/10.1007/s11119-019-09667-51 3
30. Hackfort S. Patterns of Inequalities in Digital Agriculture: A Systematic Literature Review Sustainability 2021, 13(22), 12345; https://doi.org/10.3390/su132212345
31. Cavallo E.; Ferrari ER.; Bollani L.; Coccia M. Attitudes and behaviour of adopters of technological innovations in agricultural tractors: A case study in Italian agricultural system. **2014** *Agricultural Systems*. 130. 44–54. https://doi.org/10.1016/j.agsy.2014.05.012.
32. Rogers, E.M. Diffusion of Innovations. Third Edition. In: Review Edition of Communication of Innovations. *The Free Press, New York, USA. A Division of Macmillan Publishing Co., Inc.* **1983**,
33. Rogers, E.M.; Singhal A.; Quinlan M.M. Diffusion of Innovations. In: *An Integrated Approach to Communication Theory and Research* Stacks D.W.; Salwen M.B. Eds. Second edition. NY. Routledge **2009**, 418-434.
34. Steve W. Edison, Gary L. Geissler , Measuring attitudes towards general technology: Antecedents, hypotheses and scale development, Henry Stewart Publications 1479–1862 (2003) Vol. 12, 2, 137–156 Journal of Targeting, Measurement and Analysis for Marketing.
35. Eagly, A. H. and Chaiken, S. (1993) 'The psychology of attitudes', Harcourt Brace, Fort Worth, TX (1993).
36. Ajzen, I., Fishbein, M. Understanding and predicting social behavior, Prentice Hall, Englewood Cliffs, NJ, 180
37. Ajzen, I. Nature and operation of attitudes, Annual Review of Psychology, Vol. 52, pp. 27–5, 2001
38. Elias, S.M., Smith, W.L., Barney, C.E.: Age as a moderator of attitude towards technology in the workplace: work motivation and overall job satisfaction. Behav. Inf. Technol. 31(5), 453–467 (2012). https://doi.org/10.1080/0144929X.2010.513419
39. Kim Y. G, Woo EConsumer acceptance of a quick response (QR) code for the food traceability system: Application of an extended technology acceptance model (TAM) . Food Research International Volume 85, 2016, Pages 266-272
40. Davis D., Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology, MIS Quarterly Vol. 13, No. 3 (Sep., 1989), pp. 319-340 (22 pages)
41. Chuang J.-H. & Wang J.-H. & Liang C., 2020. "Implementation of Internet of Things depends on intention: young farmers' willingness to accept innovative technology," International Food and Agribusiness Management Review, International Food and Agribusiness Management Association, vol. 23(2), May.
42. Veltheim von, F. R., Theuvsen, L., & Heise, H. (2022). German farmers' intention to use autonomous field robots: A PLS-analysis. *Precision Agriculture*, *23*(2), 670–697. https://doi.org/10.1007/s11119-021-09854-3.
43. Veltheim von, F. R., & Heise, H. (2021). German farmers' attitudes on adopting autonomous field robots: An empirical survey. *Agriculture (Switzerland)*. https://doi.org/10.3390/agriculture11030216
44. Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425–478. https://doi.org/10.2307/30036540

45. Gingrich Paul, 2020, Chi-square Tests and Table of the Chi-square distribution (Chapter 10) [in] Social Studies 201 Text. Introductory Statistics for the Social Sciences, Department of Sociology and Social Studies, University of Regina, electronic document, url: https://uregina.ca/~gingrich/ch10d.pdf
46. Altman, N., Krzywinski, M. Interpreting P values. Nat Methods 14, 213–214 (2017). https://doi.org/10.1038/nmeth.4210
47. Thomas Sellke, M. J Bayarri & James O Berger (2001) Calibration of ϱ Values for Testing Precise Null Hypotheses, The American Statistician, 55:1, 62-71, DOI: 10.1198/000313001300339950
48. Gingrich Paul, 2020, Measures of Association (Chapter 11) [in] Social Studies 201 Text. Introductory Statistics for the Social Sciences, Department of Sociology and Social Studies, University of Regina, electronic document, url: https://uregina.ca/~gingrich/ch11a.pdf
49. Lee, D. K. (2016). Alternatives to P value: Confidence interval and effect size. *Korean Journal of Anesthesiology*, 69(6), 555–562. https://doi.org/10.4097/kjae.2016.69.6.555
50. SPSS Tutorials, Z-Test for 2 Independent Proportions – Quick Tutorial, electronic document accessed 22-01-2024, https://www.spss-tutorials.com/z-test-2-independent-proportions/
51. Pfaff Ben, Darrington John et. al. GNU PSPP (Version 1.6.2). Free Software Foundation. http://www.gnu.org/software/pspp/
52. Daberkow, S. G.; Mc Bride, W. D. Farm and Operator Characteristics Affecting the Awareness and Adoption of Precision Agriculture Technologies in the US. 2003, *Precision Agriculture*, 4, pp. 163-177.
53. Borusiewicz, A.; Kapela, K.; Drożyner, P.; Marczuk, T. Application of precision agriculture technology in Podlaskie Voivodeship. *Agricultural Engineering*, **2016**, 20, 1, pp. 5-11. https://doi.org/10.1515/agriceng-2016-0001
54. IMAS Agri: Technologie cyfrowe w rolnictwie – przede wszystkim w dużych gospodarstwach. RAPORT IMAS AGRI, luty 2021. Available online: https://imas.pl/wp-content/uploads/2021/02/IMAS_Agri-Technologie-cyfrowe.pdf (accessed on 9.12.2023).
55. McFadden, J.; Njuki, E.; Griffin T. Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms, EIB-248, U.S. Department of Agriculture, Economic Research Service, February 2023.
56. Nicol, L.A.; Nicol, C.J. Adoption of precision agriculture in Alberta irrigation districts with implications for sustainability. The Journal of Rural and Community Development, 2021, 16, 1, pp. 152-174.
57. Clark, B.; Jones, G.D.; Kendall H.; Taylor J.; Cao Y.; Li W.; Zhao C.; Chen J.; Yang G.; Chen L.; Li Z.; Gaulton R.; Frewer L. J. A proposed framework for accelerating technology trajectories in agriculture: a case study in China. *Front. Agr. Sci. Eng.*, **2018**, 5, 4, pp. 485–498 https://doi.org/10.15302/J-FASE-2018244
58. Erickson B.; Lowenberg-DeBoer J.; 2022 CropLife Purdue University Precision Dealer Survey. 2022, Departments of Agronomy and Agricultural Economics, Purdue University. Croplife Magazine & Purdue University.
59. European Parliament, Directorate-General for Parliamentary Research Services, Daheim, C., Poppe, K., Schrijver, R., Precision agriculture and the future of farming in Europe – Scientific foresight study, European Parliament, 2016, https://data.europa.eu/doi/10.2861/020809
60. Nicol, L.; Nicol, C. Adoption of Precision Agriculture to Reduce Inputs, Enhance Sustainability and Increase Food Production - A Study of Southern Alberta, Canada. In G. Passerini, & N. Marchettini (Eds.), *Ecology and the environment*, 2018, *217*, pp. 327-337. Ashurst, United Kingdom: WIT Press.
61. Andreasen, C.; Vlassi, E.; Johannsen, K.S.; Jensen, S.M. Side-effects of laser weeding: quantifying off-target risks to earthworms (Enchytraeids) and insects (*Tenebrio molitor* and *Adalia bipunctata*). **2023**, *Front. Agron.* 5:1198840. doi: 10.3389/fagro.2023.1198840.
62. Arbuckle, J.G.; Hollis, J.; Dentzman V. Iowa Farmers' Perspectives on Precision Agriculture. Extension Report SOC 3107. **2023**, *Ames, IA*: Iowa State University Extension and Outreach.
63. Swinton, S.M.; Lowenberg-Deboer J. Global Adoption Of Precision Agriculture Technologies: Who, When And Why? In: Grenier, G.; Blackmore S. Eds., *Precision agriculture 2001: Proceedings of the 3rd European conference on precision agriculture* **2001**, 557–562. Montpellier, France: AgroMontpellier.
64. Lamb, D.W.; Brown, R.B. PA—Precision Agriculture: Remote-Sensing and Mapping of Weeds in Crops. *Journal of Agricultural Engineering Research* **2001**, 78, 2, pp. 117-125. https://doi.org/10.1006/jaer.2000.0630. (https://www.sciencedirect.com/science/article/pii/S0021863400906309)
65. Nationals Statistics. Farm Practices Survey Autumn 2019 – England. 2020, Farming Statistics, Department for Environment, Food and Rural Affairs
66. Steele D. Analysis of Precision Agriculture Adoption & Barriers in western Canada Producer Survey of western Canada. 2017, Prepared for Agriculture and Agri-Food Canada.
67. Masi, M.; Di Pasquale, J.; Vecchio, Y.; Capitanio, F. Precision Farming: Barriers of Variable Rate Technology Adoption in Italy. *Land* **2023**, 12, 1084. https://doi.org/10.3390/land12051084
68. European Parliament, Directorate-General for Parliamentary Research Services, Kritikos, M., *Precision agriculture in Europe – Legal, social and ethical considerations*, European Parliament, 2017, https://data.europa.eu/doi/10.2861/278

69. Rakun, J.; Rihter, E.; Kelc, D.; Denis, S.; Vindiš, P.; Berk, P. et al. Possibilities and concerns of implementing precision agriculture technologies on small farms in Slovenia. Int J Agric & Biol Eng. 2022; 15 pp. 16–21.
70. Bucci G.; Bentivoglio D.; Finco A.; Belletti M. Exploring the impact of innovation adoption in agriculture: how and where Precision Agriculture Technologies can be suitable for the Italian farm system? **2019**, *IOP Conference Series: Earth and Environmental Science*, 1st Workshop on Metrology for Agriculture and Forestry (METROAGRIFOR, IOP Publishing 275, 12004. https://dx.doi.org/10.1088/1755-1315/275/1/012004
71. Lowenberg-DeBoer J.; Erickson B. Setting the Record Straight on Precision Agriculture Adoption. *Agronomy Journal* **2019** 111, 4, 1552-1569. doi:10.2134/agronj2018.12.0779
72. Kordowska, M.; Baranowski, M.; Pisarek, J.; Ziemacki, Z.; Wawer, R.; Czech, T. ROLNICTWO 4.0 Identyfikacja trendów technologicznych, Narodowe Centrum Badań i Rozwoju, Warszawa 2023 ISNB 978-83-967832-1-9
73. Blasch, J.; van der Kroon, B., van Beukering, P.; Munster, R.; Fabiani, S.; Nino, P.; Vanino, S. Farmer preferences for adopting precision farming technologies: a case study from Italy, *European Review of Agricultural Economics*, **2022**, 49, 1, pp. 33–81. https://doi.org/10.1093/erae/jbaa031
74. Kendall, H., Clark, B., Li, W. et al. Precision agriculture technology adoption: a qualitative study of small-scale commercial "family farms" located in the North China Plain. *Precision Agric.* **2022**, 23, pp. 319-351 (2022). https://doi.org/10.1007/s11119-021-09839-2
75. Ferrari, E.; Bollani, L.; Coccia, M.; Cavallo, E. Working Paper Cnr-Ceris. **2013**, N 05.