

THESES OF THE DOCTORAL (PhD) DISSERTATION

ASSESSING THE ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES IN DEVELOPING COUNTRIES: HUNGARY AND KOSOVO SITUATION

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1.INTRODUCTION OF THE TOPIC AND OBJECTIVES

Precision agriculture is defined as the capacity to manage yield variability within fields, maximize profits, reduce waste, and minimize environmental impacts by enhanced automated data gathering, documentation, and through sensing and communication technologies use of this information for strategic farm decisions (El-kader & El-Basioni, 2013). Precision agriculture is an important method that can significantly assist in improving agricultural production, allow farmers to comprehend crop conditions, avoid damages, and through applying the right quantity of pesticide, nutrients, and irrigation water can enhance resource usage (Sanyaolu & Sadowski, 2024). Farmers can make decisions and implement the best practices in their field by using AI and related technologies and can alter the primitive way of agriculture through the application of disruptive technologies as blockchain, the Internet of Things, remote sensing, imaging technologies and drones (S.S., S., & Albaaji, 2024). The necessity for sustainable farming practices has become increasingly paramount as worldwide population multiplies and environmental concerns strengthen, but the cooperation of AI with precision agriculture signifies a promising avenue to tackle these challenges by optimizing resource utilization, enhancing crop management, and ultimately fostering a more sustainable and efficient agricultural ecosystem (Adewusi, et al., 2024).

Countries with small scale producers have it difficult to practice precision farming technologies in comparison with developed countries. The probability for adoption of precision farming technologies is much lower in developing countries compared to developed countries where the main reason is that its benefits are insufficient to justify costs (Cook, O'Brien, Corner, & Oberthur, 2003). The challenges of precision agriculture include the cost of precision agriculture technological equipment, farmers' financial limitations, access to credit and also the farmers' familiarity with digitization tools, and are allocated into two categories: those dealing with issues of technological control, human safety, civil liability, and privacy, and those that develop in conjunction with the advancement of precision agriculture as an autonomous technological area (Kritikos, 2017). Likewise, perceptions of net benefit, farm size, farmer educational levels and attitudes of confidence toward using precision agriculture technologies certainly affected the aim to embrace precision agriculture technologies (Adrian, Norwood, & Mask, 2005). Similarly, (Tamirat, Pedersen, & Lind, 2017) point out that farm size, farmer age, demonstration and networking events as joining workshops and exhibitions considerably influence farmers' adoption decisions. In Germany the number of farmers who are aware and informed about precision farming technologies increased from 54% in 2001 to 62% in 2007 based on the data collected during agricultural exhibitions and expert interviews (Reichardt, Jurgens, Kloble, Huter, & Moser, 2009).

1.1.The objectives and research questions

The dissertation has the following objectives:

1. Identify the main factors that influence the use of PAT in developed and developing countries,
2. Discuss about the perceptions and experience of Hungarian farmers and experts for PATs,
3. Discuss the perceptions of Kosovar farmers about PATs,
4. Identify the key drivers and barriers to adoption in Kosovo and Hungary,
5. Compare Kosovo's and Hungary's adoption level of precision farming technologies.

Correspondingly, this research will identify:

1. What are the main factors affecting the adoption of precision farming technologies in developed and developing countries?
2. Do Hungarian farmers have positive perceptions from adoption of PAT?
3. Are Kosovar farmers aware of precise farming?
4. What are the main differences of Kosovo and Hungary in terms of adoption of precision farming technologies?
5. What are the key factors influencing the implementation of precision farming technologies in Hungary and Kosovo?

2. MATERIALS AND METHODS

2.1.Research Design

This study implements a mixed-method research design, mixing primary and secondary data. The research incorporates survey data, farmer and expert interviews, and secondary data to provide a comprehensive understanding of perceptions of farmers toward PATs, challenges farmers face to adopt precision farming technologies and present the main differences of Hungary and Kosovo in terms of adoption of precision farming. The use of mixed methods ensures that there is no gap to the information collected, answers the question from a number of perspectives and variation in data collection led to a greater validity (Tashakkori & Teddlie, 2003). Furthermore, other scholars argue that 'as a methodology, involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative data in a single study or series of studies' (Cameron & Molina-Azorin, 2011).

2.2. Secondary data collection

Production and agriculture are different in every country. The average farm size is different. For instance, the average farm size in US is 179 ha (Statista, 2020), in Germany 55.8 ha (EUROSTAT, 2010), 29 ha in

Hungary (KSH, 2023), 67 ha in Denmark (FAO, THE STATE OF DENMARK'S BIODIVERSITY FOR FOOD AND AGRICULTURE, 2016), and 7ha in Poland (FAO, COUNTRY REPORT ON THE STATE OF PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE, 2008). Consequently, for secondary data, a conceptual framework is developed to analyze the factors affecting the adoption of precision farming technologies in developed and developing countries. The literature is collected from 1999 to 2023 through Scopus and Google scholars, and a review of the findings of PAT adoption studies is done. Many scientific articles were found, but only empirical papers were selected. A total of 31 empirical papers on factors influencing the adoption of precision farming technologies were collected.

2.3. Primary data collection

For primary data 30 interview questionnaires among Hungarian farmers and 30 survey among Kosovar farmers were collected. In Kosovo, a semi-structured questionnaire was conducted with farmers in Kosovo. A semi-structured questionnaire constitutes a mixture of closed or fixed response questions, quick response ranking or rating scales and open-ended questions (Wright & Wright, 2016). Similarly, it includes questions with response options and open-ended questions so the respondent can response in their own words (Bailey & Handu, 2013). Likewise, it comprises mostly fixed questions with few answer codes and allows interviewers to explore and enable respondents to enhance other significant problems (Bowling, 2005). Hence, the primary data of our study is generated through a semi-structured questionnaire with farmers in crop production in the territory of Kosovo, based on random selection. The list of farmers was taken from the list of beneficiaries of subsidies and grants from the Ministry of Agriculture and Forestry in the Republic of Kosovo. A total of 30 questionnaires were taken into consideration for analysis. The questionnaire consists of semi-structured questions. The first part of the questionnaire encompasses descriptive data of the farm with open-ended questions to get more general descriptive information about sampled farms. In the second part we were able to identify the obstacles of farmers in using the PA, their knowledge about it, government support about their use, their plans for near future, and other related matters.

On the other hand, an unstructured interview questionnaire is carried out in Hungary with farmers in crop production, based on random sampling. Unstructured interviews are used mostly in exploratory situations as providing background for defining a conceptual model and for more interest study of individuals mental processes like perceptions, attitudes and motivation (Kumar, 2008). Similarly, unstructured interviews are like conversations, involve little standardization and are not equally distributed (Bailey C. A., 2007). However, an unstructured interview can be more adaptable, letting the correspondent switch to the sequence of discussion, which in return is more likely to create new hypotheses than structured surveys (Axinn & Pearce, 2006). A total of 30 interview questionnaires were carried out. The questionnaire consists of semi-structured questions. The contact of Hungarian farmers was provided by the help of my supervisor Prof. Dr. Balogh Peter. The objective is to gather data about the use of precision farming technologies and their perceptions about the adoption of PATs.

2.4. Data analysis methods

For secondary data, a Mediated Causal Conceptual Framework Model is developed to analyze the factors affecting the adoption of precision farming technologies in developed and developing countries. A mediated causal conceptual framework model enlightens how an independent variable affects a dependent variable indirectly through one or more mediator variables, and its main components are: a) Independent Variable (IV) which is supposed to make adjustments in the dependent variable, b) Mediator Variable (MV) which clarifies the way the independent variable impacts the dependent variable, and c) Dependent Variable (DV) which its result is predisposed by an independent variable through a mediator variable (Baron & Kenny, 1986). Likewise, it employs a well-defined distinction between direct and indirect effects through the counterfactual framework (Byeon & Lee, 2023).

Moreover, for primary data a thematic analysis was conducted to present the perceptions of farmers in Kosovo and Hungary. Thematic analysis is a process for encoding qualitative data which requires an explicit code and enables those who use different qualitative methods to communicate with each other and allows the researcher to translate observations (Boyatzis, 1998). On the other hand, a Diffusion of Innovation Theory was developed to identify key factors that influence the adoption of precision farming in Kosovo and Hungary, using five elements of theory of Everett Rogers: relative advantage, compatibility, complexity, trialability and observability. Specifically, compare the situation between two countries and highlight the main drivers and barriers in the implementation of PATs. Diffusion of innovation theory first introduced by Everett Rogers in 1962 (Rogers, Diffusion of Innovations, 1962; 1971; 1983), is a social process in which subjectively perceived information about new idea is communicated from one person to person, and consists of five elements (variables): relative advantage, compatibility, complexity, trialability and observability which help determine an innovation 'rate of adoption and identify key factors that influence the adoption of a certain innovation (Rogers, Diffusion of Innovations, 5th Edition, 2003).

Additionally, books, scientific journal articles and reports from Kosovo's institutions along with reports from Hungarian's institutions were also used for secondary data.

3. MAIN FINDINGS OF THE DISSERTATION

3.1. Factors influencing the use of precision farming technologies in developed and developing countries
This study implements a mixed-method research design, mixing primary and secondary data. For the secondary data, a conceptual framework is developed to analyze the factors affecting the adoption of precision farming technologies in developed and developing countries. The literature is collected from 1999 to 2023 through Scopus and Google scholars, and a review of the findings of PAT adoption studies is done. Many scientific articles were found, but only empirical papers were selected. A total of 31 empirical papers on factors influencing the adoption of precision farming technologies were collected. Published papers are based on different countries and highlight information such as country, sample, scale, analysis method, type of technologies, variables and sources.

The importance of environmental quality and length of time using PFTs were not found to affect the chance of seeing an improvement in environmental quality (Larkin, et al., 2005). However, they were aware of the negative effect of agri chemicals on health and the environment (Filho, Young, & Burton, 1999), and PAT would be profitable and would improve environmental quality (Watcharaanantapong, et al., 2014). Similarly, (Rizzo, Migliore, Schifani, & Vecchio, 2024) indicated that pathway to implement sustainable innovations can be driven by environmental principles since organic farmers had a stronger environmental perspective and were less likely to consider profit gains. Moreover, family size does insignificantly influence farmers behaviors toward adoption of PAT because farm households are resource poor as larger family (9 members) may not increase resource pool of the family especially if some family members like children are not full-time workers (Onu, 2006).

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Table 1. Scientific articles published by authors.

Country	Sample	Scale	Method	Type of technology	Variable	Source
Iran	234	Farm	Descriptive research design	Different PATs	7	(Allahyari, et al., 2016)
Brazil	148	Farm	A duration Analysis	LEISA practices	4	(Filho, et al., 1999)
Philippines	30	Farm	Binary Logit and Poisson estimators	Modern rice technologies	5	(Mariano, et al., 2012)
Iran	183	Farm	Structural equation modelling	Different PATs	1	(Far & Rezaei-Moghaddam, 2017)
USA	816	Farm	An empirical analysis	Different PATs	5	(Isgin, et al., 2008)
EU	971	Farm	A multilevel random intercept regression	Machine Guidance; VRNT	7	(Barnes, et al., 2019)
Italy	200	Farm	A context-related analysis	Different PATs	6	(Vecchio, et al., 2020)
Netherlands	111	Farm	Factors analysis	Technologies for manure separation	3	(Gebrezgabher, et al., 2015)
Global	20	Farm	A Snowball approach	Different PATs	4	(Pierpaoli, et al., 2013)
Nigeria	480	Farm	A logit econometric model	Different PATs	5	(Onu, 2006)
USA	913	Farm	Tobit regression methods	Yield Monitoring; Remote Sensing; GSS	2	(Watcharaanantapong, et al., 2012)
USA	1, 692	Farm	A nested logit model	Different PATs	3	(Nair, et al., 2011)
Denmark	178	Farm	Descriptive	Yield Mapping; Soil sampling; VRT	4	(Pedersen, et al., 2004)
Iran	27,670	Farm	Davis's acceptance model	Different PATs	1	(Salimi, et al., 2020)
Global	34	Farm	An innovation diffusion framework	Different PATs	2	(Pathak, et al., 2019)
Denmark and Germany	260	Farm	A binary logit model	GPS; Auto-guidance	3	(Tamirat, et al., 2018)
Czech Republic	228	Farm	Correlational	Different PATs	4	(KUŠOVÁ, et al., 2017)
Germany	227	Farm	Binary logistic regression model	Different PATs	3	(Paustian & Theuvsen, 2017)

Table 1. Continued.

USA	1,200	Farm	Probit and negative binomial regressions	Different PATs	5	(Kolady, et al., 2020)
USA	941	Farm	A logit model	Remote Sensing; VRT	5	(Larson, et al., 2008)
Hungary	72	Farm	Box-plot analysis	Tractor Guidance	3	(Lencsés, et al., 2014)
Brazil	119	Farm	Logit and Poisson models	Different SF technologies	6	(Pivoto, et al., 2019)
Hungary	634	Farm	Descriptive and Statistical tests	GPS; Autopilot	7	(Balogh, et al., 2020)
USA	13,783	Farm	Poisson-hurdle regression	Georeferenced precision soil testing (PST)	4	(Lambert, et al., 2014)
USA	102	Farm	Poisson regression	Different PATs	1	(Castle, et al., 2016)
USA	1,215	Farm	A multivariate probit regression	Different PATs	4	(Jenkins, et al., 2011)
Denmark and USA	198	Farm	Statistical tests	Different PATs	2	(FOUNTAS, et al., 2005)
Poland	21	Farm	Snowball Approach	Different PATs	6	(Yarashynskaya & Prus, 2022)
Australia	22	Farm	Cross-Case analysis	VRT; SST; auto-steer tractors	1	(C, et al., 2006)
India	110	Farm	Descriptive analysis	Drip and fertigation system	3	(Sangeetha, et al., 2013)
Italy	174	Farm	Cluster Analysis	VRT	5	(Masi, et al., 2023)

Source: Author's own work

In developing countries, in general the main factors that influence the decision of farmers to adopt PATs are farm size, social influence, competition, government support and complexity of technology (Nguyen, Halibas, & Nguyen, 2023). On the other hand. in developed countries, the count data analysis results of a random sample of Ohio farm operators demonstrate that various factors such as farm size, farmer demographics, soil quality, urban influences, farmer status of indebtedness, and farm location within the state, were significantly associated with the adoption intensity and probability of precision farming technologies (Isgin, Bilgic, Forster, & Batte, 2008). Apart from yield monitors with GPS, which were more likely to be adopted in counties with more cropland, more full-owner farmers harvesting crops, and fewer

part-owner farmers harvesting crops, all technologies evaluated were more likely to be adopted in counties where part-owner farmers owned more land than the amount they rented. Adoption of at least one precision farming technology was more likely in counties with more acreage in large farms, lower-valued crop production, more full-owner farmers harvesting crops, and fewer part-owner farmers harvesting crops (English, Roberts, & Larson, 2000).

Table 2. PAT adoption factors.

FACTOR	EXPLANATION	SOURCE
SOCIO-ECONOMIC FACTORS		
AGE	Younger farmers are more likely to accept the risks associated with the new farm innovation	Tamirat, et al., 2018; Lencsés, et al., 2014; Jenkins, et al., 2011; Yarashynskaya & Prus, 2022; Larson, et al., 2008;
EDUCATION	Highly educated farmers were more likely to adopt PATs.	Allahyari, et al., 2016; Mariano, et al., 2012; Gebrezgabher, et al., 2015; Pivoto, et al., 2019; Jenkins, et al., 2011; Yarashynskaya & Prus, 2022; Larson, et al., 2008
GENDER	Higher adoption for men than women	Onu, 2006
NETWORKING	Attending networking events significantly influence farmers' adoption decision	Filho, et al., 1999; Nair, et al., 2011; Tamirat, et al., 2018; Onu, 2006;
EXPERIENCE	Having a long experience in farming influence the adoption of PATs.	Paustian & Theuvsen, 2017; Lambert, et al., 2014;
FINANCIAL FACTORS		
OFF FARM INCOME	Having an additional farming business or another source of income, increases the possibility of PATs adoption.	Paustian & Theuvsen, 2017;
FINANCIAL POWER	Financial situation can influence the use of PATs.	KUŠOVÁ, et al., 2017; Balogh, et al., 2020; Jenkins, et al., 2011; Barnes, et al., 2019;
CREDIT AVAILABILITY	The likelihood of obtaining an investment loan boosts the adoption of PATs.	Yarashynskaya & Prus, 2022;
AGRO-TECHNOLOGICAL FACTORS		
FARM SIZE	Larger farms have higher adoption rate.	Filho, et al., 1999; Barnes, et al., 2019; Gebrezgabher, et al., 2015; Nair, et al., 2011; Tamirat, et al., 2018; Kolady, et al., 2020; Balogh, et al., 2020; Lencsés, et al., 2014; Castle, et al., 2016; Jenkins, et al., 2011;
APPLICATION OF IRRIGATION SYSTEMS	Those using irrigation are more likely to adopt a higher number of PATs	Mariano, et al., 2012; Castle, et al., 2016; Larson, et al., 2008;

Table 2. Continued.

TECHNOLOGICAL FACTORS		
INTERNET CONNECTION	Lack of internet access can prevent the use of PATs.	Yarashynskaya & Prus, 2022; Pivoto, et al., 2019;
INSTITUTIONAL FACTORS		
GOVERNMENT FUNDING	Access to government funding was also rated as very important factor.	Balogh, et al., 2020;
INFORMATIONAL FACTORS		
LACK OF INFORMATION	Being well updated about technological innovations increases the probability of PATs adoption.	Yarashynskaya & Prus, 2022; Balogh, et al., 2020;

Source: Author's own work.

In (Table 2) are briefly elaborated the main factors that influence the adoption of PATs based on the empirical papers that we collected and analysed. The main factors are divided and named into eight groups as: socio-economic, financial, agro-technological, technological, institutional, informational, regional and behavioural. Farm size, education, age, networking and financial power were mentioned more frequently by authors in their articles (Table 2). As a result, these are the key factors that influence the implementation of precision farming technologies. Farm size does affect the adoption of precision farming technologies in both developed and developing countries. Similarly, the main barrier found to be the high cost of entry as bigger farms tend to be more likely to adopt PATs, compared to smaller farms, but also very large farms are more likely to adopt an information intensive PAT package (Barnes, et al., 2019). Besides farm size, developing countries are more affected by lack of financial sources, lack of government support and lack of technological infrastructure, whereas developed countries are more affected by financial capacity and education.

In empirical papers that we selected and analyzed, age, education, gender, networking, and experience were mentioned as important social factors in the adoption of PATs. Younger and more educated farmers were more likely to adopt PATs. Also, farmers who had long experience in farming had a higher chance of adopting one of PATs. Similarly, having under 5 years' experience in crop farming, having between 16- and 20-years' experience in crop farming, and having more than 500 ha of arable land (Paustian & Theuvsen, 2017). Attending networking events such as workshops and exhibitions (Tamirat, Pedersen, & Lind, 2017), and the more social organizations farmers belong to and participate in (Onu, 2006),

significantly influences the farmers decision about adoption of PATs. Likewise, (Blasch, et al., 2022) supports that knowledge of fellow farmers who adopted the technology positively impacts the assessment of precision farming technology features, highlighting the value of networks. Similarly, (Meng, et al., 2023) in their research indicate that cooperative membership and technical training enhanced farmers' willingness to pay for precision pesticide technologies.

Moreover, the results of a logistic regression analysis show that predictors with positive influence on the adoption of precision farming is having an additional farming business or other sources of income (Paustian & Theuvsen, 2017). Likewise, having a sustainable economic situation (KUŠOVÁ, TĚŠITEL, & BOUKALOVÁ, 2017), and the ability to obtain bank credit is important to the adoption of PATs (Yarashynskaya & Prus, 2022). Greater income levels indicate the availability of cash reserves to support longer payback periods for the technology, which in turn develops the capacity to accommodate longer payback periods (Barnes, et al., 2019).

Likewise, farm size and application of irrigation systems were mentioned as important factors in the adoption of PATs. Larger farms are more likely to adopt PATS and those using irrigation are more likely to adopt a higher number of PATs. Similarly, farm scale had positive significance on farmer's desire to adopt precision farming technologies (Meng, et al., 2023). A study conducted in in the regions of Messenia and Thessaly of Greece indicates that environmental awareness has the most significant influence on farmers' purpose to implement precision irrigation technologies (Kakkavou, Gemtou, & Fountas, 2024).

Lack of internet access is mentioned as an important technological factor which having non access can prevent the usage of PATs. Technological basics, like the accessibility and use of smartphones, computers, and the Internet, are indicatory of the overall technological advancement of farmers and farms, since farmers who are open to new technologies are more likely to embrace PATs as smartphones come with pre-installed applications and sensors, they can partially replicate PATs and serve as their complements, or integral parts and can be used for data collection, intermediate data storage, processing, and transfer to a computer for decision-making and storage (Yarashynskaya & Prus, 2022).

Access to government funding was also rated as a very important factor. The primary obstacle to spreading of PATs is the high cost of investment but adequate information and a particular package of subsidies included in the EU's Common Agricultural Policy's "greening" component as well as the Rural Development Program would boost the spread of PATs (Katalin, et al., 2017). Similarly, Regional factors such as the industrial structure of suppliers were mentioned also in the literature we collected. Regional factors such as the presence of farmers co-operatives and industrial structure of suppliers will determine the access to and availability of PATs (Barnes, et al., 2019).

Furthermore, lack of information is also an important factor for adoption of PATs. The literature considers information awareness of PATs as an important component for adoption of these technologies from sources such as: PA tech firms, universities, farmer's Unions, Governmental Agencies, educational centers and

Extension services (Yarashynskaya & Prus, 2022). Likewise, inventive and information-seeking behavior have proven important while switching from machine guidance to variable rate technologies (Barnes, et al., 2019). Also, (Santoso, A.B., Ulina, E.S., Batubara, S.F. et al., 2024) the Indonesian government should improve farmers' skills in information technology, Global Positioning Systems (GPS), and sensor technology in agricultural sectors, and facilitate access to technology and resources in order to increase rice farmers' readiness to adopt PATs. Similarly, (Farooqui, Haleem, Khan, & Ishrat, 2024) reveals that farmers can more precisely forecast future crop yields thanks to predictive analytics, thus, the mixture of Precision Agriculture and Predictive Analytics would supply farmers access to current information that allow farmers to make sophisticated choices about crop management tactics.

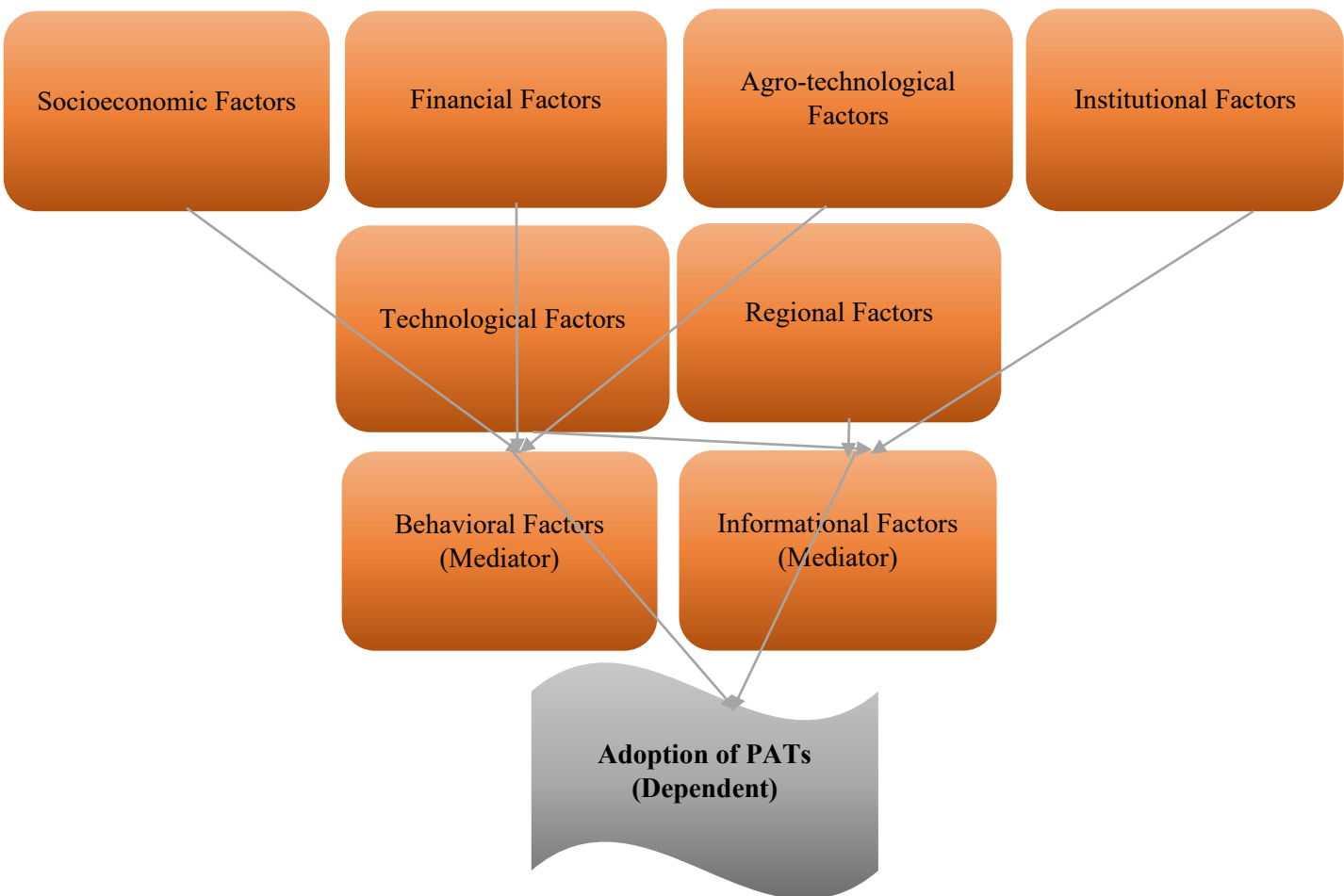
Apart from disparities in income and size, which indicate the financial burden on adoption, there is also a difference in attitude regarding the likelihood of technology uptake due to optimism about its financial return (Barnes, et al., 2019). According to (Far & Rezaei-Moghaddam, 2017), the behavioral attitude is the most important determinant of experts' intention toward the use of the precision agriculture technologies, where also attitude of confidence, perceived ease of use and perceived usefulness of precision agricultural technologies affected the behavioral attitude and behavioral intention to use.

3.1.1. Mediated Casual Conceptual Framework Model

The noted framework model (Figure 31) highlights the mediated causal relationships participating in the adoption of Precision Farming Technologies. Specifically, demonstrates how various sorts of components which are classified as independent variables, mediating variables, and a dependent variable cooperate in the adoption process of Precision Farming Technologies.

The identified factors have direct and indirect influences on the adoption of Precision Farming Technologies. Independent variables are Socio-economic factors (education, gender, networking, experience), Financial Factors (off-farm income, financial power, credit availability), Agro-technological Factors (farm size, application of irrigation systems), Technological Factors (internet connection) and Regional Factors (industrial structure of suppliers). Mediation variables are Behavioural Factors (perceived usefulness, time requirement, personality) and Informational Factors (lack of information, awareness of technology). Dependent variables are the adoption of precision farming technologies. The independent variables all have direct routes to the dependent variable. These arrows demonstrate that these factors can influence the adoption directly. For example, age and education can directly influence the farmer's decision to adopt PATs because it determines whether younger or older farmers, and non-educated or well-educated farmers are more likely to adopt PATs. Similarly, size of the farm can directly impact farmer's decision because it demonstrates whether the farm is large enough to be able to apply these sophisticated technologies. Likewise, financial power and credit availability can directly influence the farmer's decision because it determines whether they are financially stable to buy precision farming technologies

Figure 1. Mediated Causal Conceptual Framework Model of Adoption of Precision Farming technologies in developed and developing countries



Source: Author's own work.

On the other hand, mediators perform an important position whether to accept or prevent the direct impact of independent factors. These factors cooperate with mediating variables like behavioural perceptions (perceived usefulness) and informational obstacles (lack of information), to initiate the possibility of adopting PATs. Behavioural factors express farmers' attitudes and willingness in embracing new technologies, while informational factors demonstrate farmer's access to information and consciousness toward innovations. Behavioural factors can indirectly impact the farmer's choice if they see profit from technology whereas informational factors can indirectly impact farmer's choice if they lack access to adequate information about the technology, despite having strong financial background.

Networking and informational factors have indirect impact on the adoption of PATs. For example, networking allowed farmers to share information about new technologies and usage of technologies, as

without networking farmers lack awareness. A cross-regional study of EU farmers showed that information seeking behaviour evidenced significant when upgrading from machine guidance to variable rate technologies and advocated more indirect interventions such as informational support to oppose industry bias and demonstrate capability of economic profit (Barnes, et al., 2019). Similarly, a study in Denmark and Germany showed that farmers attending workshops and exhibitions had higher tendency of adopting precision agriculture practices (Tamirat, Pedersen, & Lind, 2017).

Socio-economic factors with behavioural factors can indirectly influence adoption of PATs. For instance, well-educated farmers perceive precision farming technologies as essential for expanding production and efficiency. A study made in Nebraska presented that producers expressed concern over not knowing how to interpret and use the data as well as the overall affordability and cost of the technologies producing the data even though they have seen surges in profits and productivity due to use (Castle, Lubben, & Luck, 2016). Similarly, age and behavioural factors can indirectly impact adoption of PATs. A study conducted in Denmark and Germany revealed that farmers below the age of 50 years showed a higher tendency to adopt in contrast to their older complements where in reality very young farmers lack the managerial practises and may have little understanding of adaptabilities in their farm whereas old farmers' may be liable to outdated resistance to changes and they may not see longer-term economic benefits possibly since they are reflecting retiring (Tamirat, Pedersen, & Lind, 2017). Likewise, financial and behavioural indirectly impact the use of PATs. For example, farmers who have access to micro-loans, strong financial stability and off-farm income tend to show more willingness toward PATs. Moreover, large farms perceived PATS as a lucrative investment showing more willingness to apply PATs, in contrast to small farmers which lack in willingness and confidence. A study conducted among Hungarian farmers showed that precision agriculture technologies were mostly adopted by farmers over 300 hectares and among young farmers (Lencsés, Takács, & Takács-György, 2014). Irrigation systems and informational behaviour indirectly impact the use of PATs.

Furthermore, farmers who use irrigation systems tend to be more informative towards new trends and have more willingness to adopt PATs. A study about Texas cotton producers indicates that the adoption rate of both PA technologies and VRT is positively linked with adoption of efficient irrigation technologies like center pivot and sub-surface drip irrigation systems, and the PA adoption rate was found to be higher between producers with higher irrigated cotton output (Nair, Chenggang Wang, Wang, & Johnson, 2014). Next, government funding and informational factors indirectly impact the use of PATs. For example, farmers in those countries where government who offer obligatory workshops tend to be more informed about everything new that is occurring in agriculture industry. In Philippines, government interventions to improve the educational level of farming households is needed to increase technology adoption in the long run (Mariano, Villano, & Fleming, 2012). A study in Iran indicated that performing training programs is needed for personnel staff and found that personnel and consultants with higher confidence about

employing PATs have greater intention to adopt PATs (Far & Rezaei-Moghaddam, 2017). Also, farmers with limited internet access tend to be less informed and struggle to apply precision farming technologies.

In addition, the journey to the conclusion to implement precision farming technologies is complex and not a simple procedure. The complementary diagram demonstrates that several independent factors starting from financial opportunities to features of farms, can have a significant impact in the determination process of adoption of PATs. This framework model illustrates that several factors must coordinate for these technologies to expand worldwide. Similarly, a tactical chance for investors, policymakers, researchers, agricultural experts and farmers to detect important elements regarding the application of precision farming technologies. Providing farmers access to financial sources such as credit loans and providing training programs to be familiar about PATs may markedly enhance adoption ratios. Eventually, this framework model helps in identifying the main barriers and conquer them.

3.2. Precision Farming in Hungary

Over the past years, precision farming in Hungary has shown progressive work in digital technologies and consulting services. Small scale farms experience knowledge and financial obstructions, whereas large scale farms have implemented automation, yield mapping, and RTK GPS. Hungarian farmers are aware of the two main advantages of precision farming: cost savings and maximizing production. This is confirmed by farmers who have initially started to implement precision farming technologies, who also declare economic benefits. Similarly, precision farming is vital for them to remain competitive, and younger farmers are more interested in precision farming technologies. However, there was a lack of enthusiasm among farmers, especially older ones, to employ digital technologies.

As size being an important factor for farms to adopt PATs, the same in Hungary, large scale farms (above 300 hectares) are more likely to adopt these technologies because of higher investment practicality. Similarly, large scale farms have started to apply PF technologies, while small and medium scale farms have only started to apply shared technology services. Farms being located in The Great Hungarian Plain have higher adoption rate than farms located in Transdanubia region because of the large size of farms which have reputable relations with KITE and the eastern area of Hungary has a longer past of integrating precision farming technologies. Moreover, farmers from age 20 to 70 years have adopted digital agriculture, and younger farmers have more experience and knowledge with IT based systems. Similarly, several farmers have obtained training in mechanical and agronomic sciences and hold engineering or agricultural degrees.

Despite achievements in the field of precision farming implementation, the Hungarian farming still faces various challenges. Older farmers frequently require advisory assistance due to the difficulty of making the decision to implement precision farming technologies. Likewise, due to financial constraints high-end equipment is unapproachable for small farms, have trouble acquiring actual product reviews due to a lack of knowledge-sharing networks.

3.2.1. Understanding Precision farming and what prompted the initiation of PF in Hungary?

In 2011, KITE started to introduce Hungarian farmers to precision farming technologies. However, until the end of 2014, they had been engaged in reviewing technologies, and incorporate new elements, differentiate and position input material application.

“Me, personally, around 96, 97, I came across a map showing the heterogeneity of the first such table. It was then that I saw for the first time in my life, by the way, in Germany and after that, KITE has always been in it after the technological development. I mean, what can be used in agriculture, we went after it all the time, we monitored it and what we thought could be introduced in Hungary, we tried, brought it home and tried it. It is not a simple test, but a further development, it must adapt to the Hungarian conditions, and this is how it works, this is what the company is doing and has always continued to do so for the last 45 years. And in 2010, KITE made the strategic decision that the future direction of development would be precision farming. It was then that we first began to hear about precision farming in this form. In 2010 this decision was made and in 2010 the company decided to build a separate signal service and satellite signal service system in Hungary, trying to cover the entire Hungarian arable land with this sign. It was this decision in the fall of 10, and by the fall of 2011, by the end of the year, we could say that the company was providing virtually nationwide coverage, and by developing it nicely, we had covered 300 such stations in the country in virtually a year. This network of stations allows the foundations of precision farming to be established and implemented.” (Expert).

Farmers and experts have given different definitions of precision agriculture, according to their point of view.

“What is precision farming? To answer the question, it is a form of farming that can be determined in space, provides the necessary nutrition for the plant, and carries the given repeatability. What I’ve already said is that a lot of things must come together to succeed. This starts with the sampling of the soil, the examination of the weather probes as they look at the water balance of the soil and the plant, so it can be complicated”. (Agronomist, 31 years old)

“In my opinion, PF would mean that our areas, are not very homogeneous. The fields can be quite heterogeneous, with rocky patches and sandy loam occurring. The quality of the soil also varies within the same field, and I believe that over the years, these could be cultivated in a cost-effective manner.” (Expert, 48 years old).

The use of technologies has a positive effect on those farms that have started their PF application. Farmers have managed to save time by cultivating larger areas in less time and reduce other expenses.

“In the end, we anticipated that this system would greatly assist us in our job and tasks. Well, the parallel tracking of machines, which produced extremely fine, straight, parallel lines in the field while cultivating and tilling, is truly where it all began. The machines may cultivate a wider area faster as a result. These

autonomously regulated parallel rails subsequently played a crucial role in the application of nutrients as well. Additionally, this differential allowance was included to uniformize the plants in our fields. Even in the field, I believe our yield averages have increased significantly since then.” (Production Manager, 52 years old).

Farmers have managed to reduce the use of inputs by using less fertilizer which as a result were able to increase higher returns.

“Based on the results of soil testing, we can say that the nutrient supply of our soils has not deteriorated, but we have been able to achieve even higher yields with less fertilizer.” (Production manager, 52 years old).

They have also been competent to adjust the application of fertilizer variation and volume of fertilizer very efficiently.

“Our results were at such a level that we were able to optimize the use of fertilizer very well in the case of maize. So now I think of one that there is animal husbandry as well. That is to say, we have a 100-hectare field, one end of which we have always used organic fertilizer, which is practically zero to which zero complex fertilizer had to be applied. So on the lands that received organic fertilizer, in all three years, we practically saved the price of the complex fertilizer. We had about 200-250 hectares of corn in the spring. This is already in the order of millions, as we have optimized the fertilizer variety and the amount of fertilizer. So we did not use complexes, different starters, or complex fertilizers supplemented with micronutrients, but we tried to satisfy the plant's needs with mono-fertilizers.” (Expert, 31 years old)

However, the mentality of farmers toward precision farming technologies differs from small farmers and large farmers. Farmers who own larger area of land have more willingness and a positive attitude towards the application of precision farming technologies than farmers who own a small area of land.

“Those who work on a larger area of land are more open, they are more open. Smaller farmers are not open to this because of the cost, and they cannot keep up.” (farmer, 66 years old, 70 acres).

3.2.2. Contributing factors to the expansion of innovations based on the Hungarian precision farmer’s perspective?

Lack of capital was stated as a major obstacle for implementation of PF.

“I think the bigger problem is the lack of capital. Most people who would realize that it would make sense to spend on it, have no capital or may not dare to take out a loan. And the truth is that it is very rare for a company to have a strong, good field of crop production, and they said that we introduced it, and the income that comes from it, we will start to project animal husbandry into precision as well. There are so few. There are very, very few. Those who do this are only foreigners. They clearly have more capital. So, the foreign-owned livestock companies all bought these investments.” (Expert, 53 years old).

Most farmers stated the need of training, experience, and education to facilitate the adoption of PF, while experts did not overgeneralise but think that education is not the most important criterion. These three attributes help them stay consistent with the changes that are happening in the agriculture industry, survive the competition, and stay prepared for the future.

"If farmers want to introduce PF into their farm, they'll need to educate themselves as well as gain the professional expertise and experience provided by the distributors. They'll also need to learn how these technologies operate thoroughly during training. Looking to the future, I think it matters, if not for all economies, but there are some areas and economic sizes that I think are worth doing" (65 years old, agricultural technician, 1500 hectares).

"Yes, in theory. Although the topic of education is crucial, I can also disprove it using one of my own examples. In the nation, there are exceptional precision farmers that have essentially no formal agricultural education. Nevertheless, one of the best precision farmers. I simply wouldn't generalize, though. " (Expert)

Farmers believe that they need adequate and longer training in using precision farming technologies because is not easy especially for those farmers who do not have enough knowledge about computers and latest technologies. Longer and more detailed trainings help farmers avoid technical problems that may occur while working with a tractor or while transferring the field data in the computer.

"Well, because when buying such a machine, especially when buying new ones, the sellers also provide a training, in addition to the equipment you buy, you can only talk about a few days of training here - but the basic training. So, I'm not saying you need a university degree, but it's adequate. Now a plain tractor driver who does or has completed an agricultural technical school 10 years, 15 years ago, but is not even sure that he has completed an agricultural technical school, is a tractor operator and does not have the appropriate computer training knowledge, it is very difficult, it is very difficult with him to do so to accept or do it and expect him to pay attention to what he is paying attention to, because it happens that sowing in a tractor can happen ... TECHNICAL PROBLEM" (farmer, 66 years old, 70 acres).

Another valuable indicator that has impact in the adoption of PF is farm size. Experts believe that the size of the farm is an important factor in the implementation of agricultural technologies. Farmers with small farms express less desire for these technologies because the risk investment is higher and takes a while to attain the return, whereas farmers with large farms take more risks and invest in these technologies because the return is achieved faster.

" To make the most from these technologies throughout the largest feasible field, I'd rather state that precision farming has a significant impact on your return. Because it may take a long time for a farmer with a 50–100 acre farm to return a profit. Therefore, for these devices to function effectively and affordably, large fields are truly needed." (Expert, 52 years old).

Likewise, experts mentioned that is needed for more expert advice and for more professional experts in the field of these technologies.

"It needs more expert advice than what KITE is currently putting into this topic. This is not a criticism of KITE and I am not saying that what they are doing is going in the wrong direction, I just think and let's add that there is a constant shortage of professionals in KITE as well as the economies who want it. introduce. There are few young professionals who delve into and do this at this level. And unfortunately, I have to say that these people need to be paid better than the main industry leader who has been working there for 30 years. And it's going to be hard to go through. So these young people will have the knowledge and ability to possess gold that is currently worth it. There are few people like that. " (Expert, 53 years old).

Furthermore, farmers indicated that technical support is needed in a way to facilitate decision-making in the purchase of technologies that are suitable for different farms.

"It would be excellent to have technical support for these precision instruments so that not only farmers who wish to apply PF will buy them, but also contractors who have combines and tractors will use them. I believe the issue might be addressed more thoroughly and effectively, especially for smaller farms. " (48 years old, 1200 hectares).

3.3. Precision Farming in Kosovo

Precision farming in Kosovo is still just a concept for most farmers. Most respondents are in the age group between 30-40 years. From data collection, young to middle-aged farmers show a more optimistic viewpoint toward precision farming, which aligns with global trends where younger generations are more open to adopting new agricultural technologies. Likewise, the survey incorporates both male and female respondents, with a majority of male farmers. It harmonizes with the overall tendency in the agriculture sector, where men are conventionally more active and implicated in farm activities, ownership and administration. Most farms in survey are located in the region of Prishtina (57%), and other regions as Peja, Gjakova, Ferizaj, Mitrovice, Prizren and Gjilan.

Moreover, the level of education accomplished by respondents differs. Most respondents have a master's degree, few of them have bachelor's degrees, and only 2 of them were with high school degrees. This forecasts that well-educated farmers are more prone to accept the idea of investing in precision agriculture in the near future, perchance due to a better comprehension of data-driven farming techniques, and they are more updated and tend to follow international trends in the field of farming. Most of respondents are employed outside agriculture and manage their farms as a secondary business. This predicts a positive influence toward their decisions to invest in new technologies due to their financial stability. Moreover, farms in Kosovo were established and operated since 2000, after the war ended, whereas other farms were established after 2015. Likewise, most farms are small-scale implying that they may possibly face financial

or logistical challenges in implementing precision agriculture technologies. Respondents indicated that most of the land is privately owned, while a smaller portion is leased.

3.3.1. Do Kosovar farmers have the potential to adopt precision farming technologies?

Most of the farmers in the survey supported that Kosovo has potential for the integration of agricultural technologies in Kosovar farms. They claim that Kosovo is enhancing in the field of technology. Through these technologies, they believe that their work will be facilitated, easier control and that farmers have great ambitions. While a small part of the farmers denied and said that the price and the lack of support from the Ministry of Agriculture are a barrier.

Farms are continuously improving by using advanced technological equipment, with the goal of minimizing production losses, reducing costs, and increasing profitability. One of the experts in the field of agriculture stated that given these global advancements, farms in Kosovo have the potential to adopt similar technologies, which could significantly enhance their productivity. It implies optimism about the capability of Kosovo's agricultural sector to embrace technological innovations to improve efficiency and profitability.

“Considering that farms are advancing every day with the application of the most sophisticated technological equipment and are aiming to reduce losses in production, reduce production costs and higher profitability, of course this means that in farms Kosovo has the potential for the application of technologies that increase productivity.” Expert, 18-30 years old.

Farmers emphasised the shifting focus to technology. They address how much capital and labour have already been invested in Kosovo's livestock and agriculture industries. To increase yields and reduce reliance on human labour, however, it's time to shift toward implementing technology innovations, which can boost productivity and efficiency in the sector.

"In recent years, significant investments have been made in agriculture and animal husbandry in Kosovo. I believe enough time has passed for those who have focused on investing in equipment and manual labor. Now, it is time to shift toward technological development, which will lead to tangible results—such as increased yields on one hand, and a reduction in reliance on human labor on the other." Farmer, 30-40 years old.

Likewise, they emphasised possibility of technology adoption on large farms. GIS and GPS systems, which can monitor environmental conditions and optimize fertilizer use, are most advantageous for large commercial farms.

"There are many large farms that could greatly improve the management of their agricultural land using computer systems, particularly with GIS and GPS technology. These systems can be connected to sensors programmed to detect factors such as plant type, soil moisture, temperature, and more. Additionally, they

can control the precise application of fertilizers, ensuring eco-friendly practices by allowing the choice of organic fertilizers, which are already available on the Kosovo market." Farmer, 30-40 years old.

Similarly, other farmers see large and commercial farms as having the most potential for adopting new technologies and driving innovation. These farms have the financial resources and scale to invest in advanced farming technologies, making them better positioned to lead in improving productivity and efficiency.

"Large and commercial farms hold the greatest potential for growth and innovation, as they have the resources and capacity to adopt advanced technologies and implement more efficient farming practices." Farmer, 30-40 years old.

Young farmers believe that technology is the best way to address the shortage of physical labor in agriculture. By implementing technological solutions, farms can continue to operate efficiently without relying as much on manual workers.

"Given the shortage of physical labor, it would be the ideal replacement." Farmer, 18-30 years old.

3.3.2. Usefulness of precision farming techniques in the agricultural sector of Kosovo

All respondents are optimistic toward the adoption of PATs and distinguish the prospective for enhancing productivity, increasing efficiency, and decreasing costs. Similarly, they intend to invest in precision farming technologies near the future. Most farmers apply traditional agricultural technologies such as tractor, point-point irrigation system, utility trailer, electric spraying etc., whereas only few have started using GIS monitoring and sensor technology at a distance. Likewise, almost all have shown curiosity in training and discovering more regarding precision farming. However, farmers have mostly mentioned costs and limited access to information as the main barrier to implement precision farming technologies, since the price of these technologies is high compared to their financial situation, and absence of reliable information on the performance of diverse technologies in local circumstances.

All farmers in Kosovo have admitted that precision farming technologies would benefit farmers in Kosovo and like the rest of the world, Kosovo should acknowledge technological advancements. This is seen as crucial due to the fast-paced changes in modern life in Kosovo. Technology is expected to gradually take over tasks currently handled by the labor force, which continues to face its own challenges, such as shortages and inefficiencies.

"While the whole world is oriented towards technological developments, they will also be necessary and indispensable in Kosovo, especially considering the dynamics of life which has now taken over Kosovo and the technological developments will gradually cover the labor force, which day by day it still has its own problems..." Farmer, 30-40 years old

Farmers show optimistic behavior towards the use of precision farming technologies. They believe that technology will not only make work easier but will also enhance overall performance, leading to better outcomes in agriculture or other sectors.

“I believe that the work will be easier, and the performance will be better” Farmer, 30-40 years old.

They state that farms can reduce losses, protect investments, and lower production costs by utilizing modern technologies. This features the financial and operational benefits of adopting precision farming tools and technologies.

“Through these technologies it is possible to reduce losses, save investments, reduce production costs” Farmer, 30-40 years old

According to farmers, modern technologies not only replace the need for manual labor but also offer better time management, allowing for more efficient farm operations and saving valuable time.

“It replaces the labor force, the best time management option, and saves time.” Farmer, 30-40 years old.

Farmers also highlighted the role of technology in boosting agricultural output and ensuring timely interventions, such as addressing crop needs or challenges at the right moment. This can lead to better harvests and more effective management.

“Yield increase and timely intervention in yield” Farmer, 18-30 years old.

From the expert's view, training farmers and creating awareness on the best agricultural practices are expected to enhance the adoption of precision farming technologies soon. The aim of applying these technologies is to improve production and reduce loss. Likewise, they also state that the application of computer-controlled systems and software in agriculture would result to improved quality of agricultural products. This technological innovation will also have optimistic effects on the well-being of the population, environment and make it possible for farms to produce products that are market viable. Additionally, highlights the potential of precision technology to enhance production quality, sustainability and competitiveness.

“As a result of raising farmers' awareness through training for the best agricultural production practices, in the near future more importance will be given to the application of precision equipment with the aim of greater yield gains and less losses.” Expert, 18-30 years old.

“We would have qualitative production controlled by computer and software, the well-being of the population, environmental protection, and competitive production for the market would increase!” Expert, 30-40 years old.

3.4. Comparative Analysis; A cross-country comparison

As we mentioned in chapters above, precision farming technologies are being adopted among farmers in Hungary whereas in Kosovo precision farming is still a new concept. As a result, a comparative analysis is done to analysis the current situation of two countries in terms of implementation of precision farming technologies.

Hungary has coordinated training programs for farmers, while Kosovo farmers usually learn individually or from informal resources. Hungary has a sophisticated RTK network and consulting services, whereas Kosovo up to this time is in initial adoption stages and needs structured infrastructure. Likewise, farmers in Hungary have strong government and EU support, while farmers in Kosovo face economic encounters with slight economic support. Hungary utilizes big data and AI to make decisions, whereas Kosovo is still engaged on elementary automation and GPS navigation. Similarly, Hungary confronts obstacles linked to farmer training and affordability, while Kosovo fights with fundamental infrastructure and government cooperation. Lastly, Hungary is enhancing on full automation and AI-based precision farming, while Kosovo is still developing initial precision farming practices.

Table 3. Comparative Analysis of Precision Farming Adoption in Hungary and Kosovo: Main Characteristics and Encounters

1. Category	Hungary	Kosovo
Implementation level	Progressive, nationwide RTK	Early phase, lack of infrastructure
Farmer Characteristics	Wide age range (20-70 years)	Generally younger farmers (under 40)
Education & Training	Formed training & consulting	Mainly self-learning
Government Assistance	Strong EU and government subsidies	Slight government assistance
Farm Scale	Generally large-scale (300+ ha)	Mainly small farms (under 100 ha)
Core adopted Technologies	RTK GPS, yield mapping, AI-driven automation	Mostly basic automation; Few GPS; GIS monitoring
Limitations	High investment costs, training gaps	Financial obstacles, lack of government support in PF
Prospects	AI and full automation	Gradual adoption, potential for EU funded projects

Source: Author's own affiliation.

Precision Farming Implementation level

In Hungary, precision farming has been practiced since 1996–1997, more widespread in 2010, being implemented mainly in large scale farms those above 300 ha. KITE Ltd. structured a national RTK GPS network (300 RTK stations) to facilitate high-precision automated farming. Variable rate technology

(VRT), satellite imaging, and advanced yield monitoring are all generally utilized. Since 2016, consulting services have been presented to support farmers' switch to digital agriculture. On the other hand, in Kosovo precision farming is still in the early implementation phases. There is no nationwide RTK network comparable to Hungary. Adoption is particularly by middle-aged farmers from 30-40 years old. GIS monitoring, GPS and automated seeding/fertilizing are implemented by few farmers while other technologies like advanced yield mapping and VRT are not presented.

Farmer Characteristics, Education and training

In Hungary, farmers applying precision farming technologies diverge from 20 to 70 years old, adopted particularly amongst educated farmers with degrees in agronomy or engineering while older farmers are more hesitant to embrace modern technologies. Likewise, several large-scale farms train their staff in IT-based precision farming. On the other hand, in Kosovo younger farmers (under 40) are more interested in new technologies, and those with better education are more prone to invest in digital equipment. Likewise, information and overall knowledge about precision farming is generally gained through self-learning.

Government support

In Hungary, the implementation of precision farming technologies is aided by government and EU subsidies. The beneficiaries of subsidies and grants are usually large farms. Likewise, in order to reduce the expenses, farmers devolve on machine rental services. Conversely, in Kosovo there is not a committed government or EU subsidies for precision farming. Likewise, it is quite challenging for small scale farms which are typically under 100 ha to invest in these technologies where many of them are impotent to adopt new technologies because of the high initial expenses and are still dependent on traditional farming practices.

Core adopted precision farming technologies

In Hungary, exists a completely advanced RTK GPS systems. Similarly, enhanced automated steering, yield mapping, precision seeding/fertilization, and large data analysis and AI-powered automation are employed by farmers to come to a decision. On the other hand, in Kosovo there are few precision farming technologies in utilizing, particularly GIS, GPS and automated machinery. Similarly, there is a lack of consolidated programs for farmers to exchange expertise in relation to modern technologies.

Limitations in Precision Farming Adoption

In Hungary, older farmers are reluctant to implement new technology, and for small and medium farms, precision farming technologies are quite expensive that require high initial cost. Likewise, there is a need for IT-skilled labor, and few individual testing facilities to estimate technology execution. On the other hand, Kosovo does not have a centralized RTK network for precision farming to support precise machine guidance which would make the adoption process much easier, and a lack of government assistance in the field of precision farming. Likewise, the high cost of these technologies is quite challenging for Kosovar

farmers, notably for those who own small farms, and there is little approach to professional expertise and regulated training.

Prospects of precision farming implementation

With an objective to expand its extent to 1 million hectares, the growth of AI-driven automation, drone monitoring, and data analytics is transforming precision farming in Hungary. This alteration is encouraged by increased consulting services and education programs to supply farmers with the required knowledge and skills. A great prominence on digital transformation and automation seeks to augment productivity, adjust resource use, and amend general agricultural output. On the other hand, in Kosovo moderate adoption of GIS monitoring is opening the door for other precision farming technologies. Even though interest among young farmers is increasing, extensive implementation is still hindered by the lack of coordinated policy aid. Nonetheless, the alteration to high-tech precision farming may perhaps be enhanced by the likelihood of EU-funded agricultural innovation projects.

3.4.1. Framework Analysis: Diffusion of Innovation Theory

A Diffusion of Innovation Theory was developed to identify key factors that influence the adoption of precision farming in Kosovo and Hungary, using five elements of theory of Everett Rogers: relative advantage, compatibility, complexity, trialability and observability (Rogers, Diffusion of Innovations, 2003). Specifically, compare the situation between two countries and highlight the main drivers and barriers in the implementation of PATs.

Table 4. Framework analysis: Diffusion of Innovation Theory

DOI ELEMENT	HUNGARY	KOSOVO
RELATIVE ADVANTAGE	- <i>High</i> (Time saving, higher production and decreased input usage; Large farms outline substantial profit gains.)	- <i>Low</i> (Expensive technologies; Struggling with financial resources hampers small farms.)
COMPATIBILITY	- <i>High</i> (Corresponding with large-scale farms; Opposition from small farmers who favour conventional practices.)	- <i>Moderate</i> (Corresponding with small scale farms; Less with small scale farms which encounter financial and fundamental obstacles.)
COMPLEXITY	- <i>Moderate</i> (Farmers encounter challenges in understanding and employing PAT; Due to not enough training, older farmers strive with technological practices and knowledge.)	- <i>High</i> (Need for training since farmers lack in using and understanding PAT; Younger farmers are more receptive to learn about PAT but deficient in technical knowledge.)
TRIALABILITY	- <i>High</i> (In cooperation with government and companies, farmers can experiment technologies on small schemes; With the aid of trial projects, larger farms alleviate risk.)	- <i>Low</i> (Limited capacity for tests; smaller farms have insufficient sources for conducting tests whereas large farms may conduct tests; Trial projects are essential to show capability and advantages.)

OBSERVABILITY	- <i>High</i> (Success of large farms motivates smaller farmers to adopt; Actual cost and being profitable pushes implementation of PATs between farmers or potential investors.)	- <i>Low</i> (Farmers depend on international developments for motivation due to nonlocal examples of success stories on the adoption of PATs; Necessity for local success stories to encourage implementation of PATs among farmers.)
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Source: Author's own work.

Relative Advantage

Farmers in Hungary are aware of the financial benefits that precise farming technologies bring such as higher yields, lower input costs, and increased efficiency. To make it more financially feasible for large scale farms, government and EU subsidies assist in reducing adoption costs. Likewise, consulting services help farmers maximize technology advantages. On the other hand, due to the high investment expenses, farmers in Kosovo are unable to see economic benefits. Similarly, farmers are strained to pay full price for technology due to a lack of government assistance, which slows the interest in implementation and many of them are unwilling to adjust from traditional farming to precision farming.

Compatibility

In Hungary large scale farms can more easily implement precision farming since these technologies enhance productivity. Likewise, precision farming technologies are easier to implement because many farmers already employ digital devices. Understanding of precision farming technologies and traditional technologies expertise is ensured by using prepared training programs. On the other hand, in Kosovo the cost of precision farming technology is complicated to justify on small scale farms. Similarly, with little experience of modern equipment, many farmers remain to employ old techniques. Older farmers are unwilling to adjust and still choose traditional manual practices upon modern, data-driven approaches.

Complexity

Precision farming technologies like yield mapping, RTK GPS operation, and AI-based decision-making all require IT skills. As a result, in Hungary farmers, especially older farmers require training, so KITE Ltd.'s advising services enable farmers to adjust into precision farming technologies by providing training programs.

In Kosovo, many farmers are not digitally literate, therefore employing precision farming tools and software can be quite difficult. Since there are no formal school programs, farmers must learn individually. Similarly, lack of access to experts in the field of precision farming technologies or any digital tools causes uncertainty and unwillingness in farmer's decision to embrace new technologies.

Trialability

Before making an important step into investing in precision farming technologies, farmers can test the technology by renting precision farming equipment. Likewise, real-world success presented by pilot programs and adoption farms offer farmers substantial confidence to embrace new technologies in their farms. Similarly, farmers can progressively apply automation and RTK GPS owing to KITE Ltd. and government-supported initiatives. On the other hand, in Kosovo the lack of government-backed pilot projects makes farmers reluctant to employ precision farming technologies since there are no trial prospects and no equipment rental programs.

Observability

In Hungary, there are several successful precision farming initiatives, which allows farmers to see the positive side of PATs and practical advantages. Likewise, farmers can observe the effects of precision technologies through KITE Ltd., adoption farms which serve as case studies for Hungarian farms. Similarly, sharing knowledge and experience between farmers raises mindfulness and willingness to give a chance to precision farming technology. On the other hand, in Kosovo farmers find it challenging to believe in the benefits of precision farming due to a lack of reliable case studies. Lack of networks and training programs for exchanging knowledge and experience, consequently farmers depend on more on word-of-mouth than on education training. Farmers are doubtful because they haven't seen sufficient data of success under the conditions in Kosovo but only from online stories of farmers in developed countries.

We have already compared the two countries (Kosovo and Hungary) so far, noting the main differences that both countries have, yet we have not discussed about the similarities they have in the implementation of precision farming. In both countries, small-scale farmers face substantial challenges due to a lack of financial support, whereas large farms are more likely to adopt precision farming technologies because of easier access to funds. Similarly, for both countries, adoption is more practicable and beneficial for large farmers since economies of scale justify investment. In other words, precision farming involves an important investment, in which large farms can have enough money compared to small farms and have it easier to recuperate investments over the years and large farms encounter better cost savings and productivity enhancements compared to smaller farms, making precision farming more useful for them. Likewise, in both countries, to overcome the technical struggles of PF farmers highlight the value of training.

In addition, Kosovo is still in early phase of implementation in comparison with Hungary who has a more advanced implementation phase which is reinforced by better experimental and evident methods. In other words, in Hungary farmers have the chance to test precision farming technologies before making the decision to invest in them, and there are a lot of success stories of early adopters in Hungary who serve as a proof for farmers to trust precision farming technologies, whereas farmers in Kosovo demonstrate potential but needs stronger economic, informative, and institutional support schemes to make it to Hungary's level of implementation.

3.5. Frequency Analysis



Figure 2. Most frequently used words.

Source: Author's own work.

The frequency analysis (Figure 32) of the text reveals that precision farming is the central topic, with words like "precision" (625 occurrences), "farming" (470), and "respondent" (392) appearing most frequently. The high occurrence of "precision" and "farming" supports that the conversation revolves across precision farming implementation. The words "think" (499) and "say" (473) indicate that the content involves opinions and discussions and demonstrates that the text is probably obtained from surveys and interviews with farmers and experts. The word cloud visualization supports this, emphasizing words like "questioner" and "respondent". This indicates that the dataset involves farmer feedback and expert opinions. Moreover, words like "know," "good," and "years" indicate conversations on experience, knowledge, and long-term movements in precision farming adoption. The vocabulary concentration (0.052) specifies a high level of word recurrence. It demonstrates that certain ideas control the discussion, strengthening the idea that the text is focused more on agricultural topics instead of including other topics. In general, the occurrence information implies a highly discussion-oriented document, where farmers and experts provide their opinions on the influence, viability, and prospect of precision agriculture, with a spotlight on real-world practices and practical relevance.

4. NEW AND NOVEL RESULTS OF THE DISSERTATION

The research provides several novel findings which can be derived from the analysis. The main novelty is the presentation of two different perspectives on the implementation of precision technologies, where we have one country that has started implementing them and another that is still in the early stages of its use. This will serve as a good example for potential Kosovar farmers and other potential farmers from small developing countries to encourage them to make investment decisions toward precision farming technologies.

Another novel finding is the financial gaps between large and small farms. In Hungary, large scale farms have been capable to incorporate automation, yield mapping, and RTK GPS, in contrast with small farms which stumble because of financial limitations. Similarly, in Kosovo, large scale farms have more capability in the adoption of precision farming technologies compared with small scale farms.

Another novel finding is the importance of visible success and experimental use. The research indicates that Hungary's success in implementing precision farming technologies is because of visible success of farmers that adopted PATs and experimental use of these technologies where farmers can assess technologies via rental programs before making the right decision for investment. The opposite case is with Kosovo which stands in need of trial programs in order to provide their farmers with the opportunity to try precision farming technologies.

Moreover, emphasizing the role of education and training in adoption of PATs is another novel finding. Formal education is not the only predictor of adoption since some highly skilled precision farmers in Hungary do not possess formal education but have obtained skills and knowledge through training and industry cooperation. Hence, this indicates that training and consulting services might be as significant as formal education for adopting digital technologies. Whilst Hungary has training programs and university partnerships, Kosovo have not such supported programs. Equally, Kosovo's farmers are interested in digital technologies but due to the high cost and lack of training they need institutional assistance. They mainly rely on personal experience and self-learning. Similarly, many Kosovar farmers in the survey revealed positive attitude for implementing precision farming, simply mentioned cost and lack of government assistance as key obstacles.

6.CONCLUSION AND SUMMARY

Precision agriculture is a method of managing the entire farm that makes use of information technology, GNSS data, remote sensing, and close-proximity data collection (European Parliament, 2014). Precision agriculture was first defined by US House of Representatives (1997) as “An integrated information and production based farming system that is designed to increase long-term site-specific and whole-farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment” (Whelan & Taylor, 2013). It is often defined by the technologies, such as GPS (Global Positioning System), GIS (Geographic Information Systems), autosteer, yield monitors, and variable rate fertilizer which are shifting agriculture, and implementing opportunities to diminish the negative environmental effects (Shannon, Clay, & Kitchen, 2020). The aim of this research is highlighting the key factors that influence the implementation of precision farming technologies in developed and developing countries; presentation of current situation of precision farming adoption in Hungary and Kosovo; and analyze the main factors that influence the implementation of precision agriculture technologies in Hungary and Kosovo. Similarly, introduction of precision farming technologies to farmers in Kosovo and present their perceptions and knowledge about PA technologies. In addition, this research presents two different perspectives of farmers in Hungary and Kosovo and discusses the differences between two countries.

The findings of the conceptual framework development on factors influencing the adoption of PATs in developed and developing countries indicate that farm size, education, age, networking and financial power were mentioned more frequently by authors in their articles. As a result, these are the key factors that influence the implementation of precision farming technologies.

Precision farming in Hungary has shown progressive work in digital technologies and consulting services over the past years. Likewise, small scale farms experience knowledge and financial obstructions, whereas large scale farms have implemented automation, yield mapping, and RTK GPS. On the other hand, precision farming in Kosovo is still in early stages of development. The findings indicate that in Hungary farmers have the chance to test precision farming technologies before making the decision to invest in them, and there are a lot of success stories of early adopters in Hungary who serve as a proof for farmers to trust precision farming technologies, whereas farmers in Kosovo demonstrate potential but needs stronger economic, informative, and institutional support schemes to make it to Hungary’s level of implementation. However, in both countries, small-scale farmers face substantial challenges due to a lack of financial support, whereas large farms are more likely to adopt precision farming technologies because of easier access to funds. Similarly, for both countries, adoption is more practicable and beneficial for large farmers since economies of scale justify investment. In other words, precision farming involves an important investment, in which large farms can have enough money compared to small farms and have it easier to

recuperate investments over the years and large farms encounter better cost savings and productivity enhancements compared to smaller farms, making precision farming more useful for them. Likewise, in both countries, to overcome the technical struggles of PF farmers highlight the value of training.

7.LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

1. Maloku, D., Balogh, P.: Factors influencing the adoption of Precision Farming Technologies in developed and developing countries: A Mediated Causal Conceptual Framework Model. Journal of Agricultural Informatics. [Accepted by publisher], 1-9, 2025. EISSN: 2061-862X.
2. Maloku, D.: Adoption of precision farming technologies: USA and EU situation. SEA: Practical Application of Science. 8 (22), 7-14, 2020. EISSN: 2360-2554.
3. Maloku, D., Kovács, K., Shkodra, R.: An economics assesment of poultry egg sector in Kosovo. Network Intelligence Studies. 8 (15), 71-79, 2020. EISSN: 2344-1712.
4. Shkodra, R., Felföldi, J., Kovács, K., Maloku, D.: Technical efficiency of dairy farms in Central Kosovo. International Journal of Economics and Financial Issues. 10 (4), 258-263, 2020. EISSN: 2146-4138. DOI: <http://dx.doi.org/10.32479/ijefi.9630>
5. Maloku, D., Balogh, P., Bai, A., Gabnai, Z., Lengyel, P.: Trends in scientific research on precision farming in agriculture using science mapping method. International Review of Applied Sciences and Engineering. 11(3), 232-242, 2020. ISSN: 2062-0810.
DOI: <http://dx.doi.org/10.1556/1848.2020.00086>
6. Bai, A., Gabnai, Z., Kovách, I., Czibere, I., Nagy, J., Sulyok, D., Maloku, D., Balogh, P.: Economic analysis of some agrotechnical factors in maize production - a Hungarian case study. Apstract. 13 (3-4), 5-16, 2019. ISSN: 1789-221X.
DOI: <http://dx.doi.org/10.19041/APSTRACT/2019/3-4/1>

Conference, presentations

1. Presenter in the Conference of the Doctoral School, the title of the conference was 'Young researchers for talent' at University of Debrecen, the article name (Adoption of Precision farming technologies in the USA, EU and rest of the world) that held on 22nd November 2019.
2. Conference of the Doctoral School, 'Young researchers for talent' at University of Debrecen, 16th November 2018;
3. Presentation and workshop organized by The Károly Ihrig Doctoral School of Management and Business, The title of the presentation: "Best practices regarding conceiving, writing and publishing a scientific article in Business & Economics" at the University of Debrecen, 23-24 of April 2019;

4. International Jean Monnet Conference, the title of the conference was “Development of the border regions in Central and Eastern Europe countries (DBRCEEC)” at University of Oradea, held during 5-7 November 2019;
5. Conference of the Doctoral School, 'Young researchers for talent' at University of Debrecen, 22nd November 2019.

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