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DONIKA MALOKU

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Head of the Doctoral School: **Prof. Dr. Balogh, Peter professor, DSc**

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

Prepared by:

Donika Maloku

Supervisor:

Prof. Dr. Balogh Peter

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The aim of this dissertation is to obtain a doctoral (PhD) degree in the scientific field of „Management and Business”

Written by: …………………………… certified ……………………………

Supervisor: Dr. ……………………………

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DECLARATION

I undersigned (name: Donika Maloku date of birth: 09 March 1993) declare under penalty of perjury and certify with my signature that the dissertation I submitted in order to obtain doctoral (PhD) degree is entirely my own work.

Furthermore, I declare the following:

- I examined the Code of the Doctoral School of Management and Business Administration and I acknowledge the points laid down in the code as mandatory;
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- I indicated the original source of other authors' unpublished thoughts and data in the references section in a complete and correct way in consideration of the prevailing copyright protection rules;
- No dissertation which is fully or partly identical to the present dissertation was submitted to any other university or doctoral school for the purpose of obtaining a PhD degree.

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CONTENT

INTRODUCTION

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., et al., 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).

Technological advancements support enhancement of crop yields and get better farming results through sustainable ways, especially in those countries where more than 70% of the population relies on agriculture for their living, and will also push the next generation to take up agricultural jobs (S.S., et al., 2024). Food is provided to us by arable land which also supplies us with clothing, home, industrial items, and fuel and due to the withdrawn of land in industrialized nations for construction, manufacturing, transportation, and other uses, agriculture must be improved to sustain production (Oliver, 2013). The United Nations which proposed a sustainable goal to encourage the spread of innovation in agriculture, such as IT and smart solutions for organizing the production and sale of food products, has become an important goal not only for the growth of a country's primary sector but also for the whole global economic system (Vecchio, et al., 2002). Sustainable agriculture refers to the long-term improvement of environmental quality and natural resources, providing people with the nutrients they need for food, economically viable, and enhances the standard of living for farmers and society at large (Bongiovanni & Lowenberg-

Deboer, 2004). Long-term support or durability are implied by the word "sustain," which comes from the Latin sustinere (sus-, from below and tenere, to keep in existence or maintain), and was first addressed by Congress in the 1990 "Farm Bill" (Food, Agriculture, Conservation, and Trade Act Of 1990 (FACTA) (Gold, 1999). Correspondingly, in the 1990 Farm Bill, the U.S. Congress defined sustainability as ”an integrated system of plant and animal practices having a site-specific application that will over the long term: satisfy human food and fiber needs, enhance environmental quality and the natural resource base upon which the agriculture economy depends, make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls, sustain the economic viability of farm operations, and enhance the quality of life for farmers and society as a whole” (Koohafkan, 2011).

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, et al., 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, et al., 2005). Similarly, (Tamirat, et al., 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, et al., 2009).

Correspondingly, a minimum three criteria are essential for the employment of precision agriculture such as clear evidence of significant spatial and temporal variability in soil and crop conditions within a field and in fields within a region, ability to identify and quantify such variability and ability to reallocate inputs and adjust management practices to improve productivity and profitability while minimizing environmental degradation (Srinivasan, 2006).

(Raj, et al., 2019) explained the precision agriculture cycle in following steps:

1) **Data collection** – Measuring, monitoring and mapping within-field variability in soil, crop parameters and weather conditions;
2) **Data interpretation** –Using different crop models, image interpretation or data assimilation techniques, can be identified and interpreted spatially variable parameters;
3) **Application** – Based on the results of processed data, farm management can be customized for the right place, the right time and the right amount.

Similarly, (Escola & Kerry, 2021) supported that precision agriculture can be practiced in 4 stage steps such as: data gathering about the crop and its environment, data processing and information extraction, decision making and operation in the field.

Moreover, as claimed by the U.S Department of Agriculture and Purdue University, in the upcoming years, an average of 60,000 high-skilled ag and similar opening jobs are expected annually in the U.S filling up the job positions in agriculture, food, renewable resources and environment (Daniels, 2015). Respectively, some of Universities and Colleges are providing programs in precision farming for students who are interested in pursuing a career in the modern agriculture by monitoring and better running the farm operations where the majority of Universities are located in the USA whereas the others in New Zealand, Canada, and Australia, and in 2018, the number of students enrolled in these universities is ranging from 10 students in Colorado State University and the University of Minnesota to 120 students in Massey University and Iowa State University, consequently, in New Zealand and Iowa students have been showing higher interest in the precision farming program (Hopkins, 2018). Agriculture is becoming more attractive to the young generations.

However, most technologies used in precision agriculture require adequate knowledge and skills to be used accurately. Consecutively, various jobs are more likely to be generated and the demand for skilled labor is needed. People have started to realize that this sector is not traditional anymore, but it is transforming into a modernized industry with a diverse job opportunity (Daniels, 2015). Precision farming technologies such as GIS, remote sensing, global positioning system, and weather data need adequate knowledge and skills in ordering these technologies to be used accurately.

As stated by (Kitchen, et al., 2002) the optimal value of information for precision agriculture will be best achieved by producers, agribusinesses, and educators as they improve their:

a) Agronomic knowledge and skills,
b) Computer and information management skills, and
c) Understanding precision agriculture as a system for increasing knowledge.

1.MAIN TOPICS AND OBJECTIVES

In this chapter the research background, objectives, questions, and importance of the study will be explained. Likewise, briefly offers a summary of the structure of thesis.

1.1. Research Aims

Hungary, a country with a long tradition in farming, a rich and suitable soil has started to implement PA technologies. Therefore, this research will discuss about the experiences and perceptions of Hungarian farmers and experts about precision farming technologies. On the other hand, in Kosovo, precision farming is still a new concept. Kosovo, apart from mineral resources, is rich in fertile soil, young and ambitious population and has good climate conditions which makes it possible for rapid development of agriculture, and the economy in general. Nevertheless, Kosovo is characterized by small scale farms, low productivity and lack of introduction of new methods. Therefore, 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, to introduce precision farming technologies to farmers in Kosovo and present their perceptions and knowledge about PA technologies. In addition, this research will present two different perspectives of farmers in Hungary and Kosovo and discuss the differences between two countries.

1.2. Research Objectives

The dissertation has the following objectives:

- Identify the main factors that influence the use of PAT in developed and developing countries,
- Discuss about the perceptions and experience of Hungarian farmers and experts for PATs,
- Discuss the perceptions of Kosovar farmers about PATs,
- Identify the key drivers and barriers to adoption in Kosovo and Hungary,

- Compare Kosovo’s and Hungary’s adoption level of precision farming technologies.

1.3. Research questions

Correspondingly, this research will identify:

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

1.4. Structure of the thesis

This section provides an outline of the direction that will be followed to attain the research objectives, questions, structure, literature review, data and methods, analyses, findings, discussion, and main conclusions.

Chapter 1 involves introduction to provide adequate background information of the research topic that is discussed in further chapters. Similarly, it helps the reader understand the meaning and the concept of the research topic.

Chapter 2 involves the main topics and objectives of the research topic. In detail, it presents research aims, research objectives, research questions and structure of the thesis. This chapter will help the reader understand what the researcher wants to accomplish through this study.

Chapter 3 includes literature review. The review will cover the evolution of technology in farming, a theoretical background of precision agriculture, main tools and techniques of precision farming (in which will be discussed about each technology separately), comparison of precision farming and conventional farming, adoption of precision farming technologies and its benefits and challenges, and the state of agriculture in Kosovo and Hungary.

Chapter 4 will discuss the accepted methodology.

In **Chapter 5** the analysis of qualitative data will be presented. The analysis includes conceptual framework development, a thematic analysis and a comparative analysis. A conceptual framework is developed on finding the factors influencing the adoption of precision farming technologies. Thematic analysis is conducted to present the perceptions and views of farmers toward precision farming technologies. A comparative analysis is done to present the differences between two countries (Kosovo and Hungary).

Chapter 6 presents the conclusion and summary of the research.

Chapter 7 discusses limitations and future studies.

Chapter 8 discusses novelty findings and recommendations.

The dissertation ends with references, a list of tables and figures, publications, and appendixes.

2. LITERATURE REVIEW

2.1.The evolution of technology in farming

Following several important famines in the 1950s and 1960s, agricultural development during the next two decades was primarily focused on achieving food security and preventing hunger in developing countries, where as a result of these challenges sparked the Green Revolution, which was characterized by the adoption of high-yielding wheat and rice varieties, which doubled or even tripled crop yields in just 20 years (Otsuka & Fan, 2021). Increased input utilization, productivity growth, higher use of modern inputs like fertilizer, improved seeds, water, as well as increases in input quality such as better-educated labor and upgraded tractors, have historically been the main sources of growth in agriculture (Rosegrant, et al., 2021). The word agriculture is derived from the Latin word “Agricultura” translated to "care of soil”, which addresses the challenges of food and fiber production and processing comprising techniques for cultivating soil, growing and harvesting crops, raising animals, and processing plant and animal materials for use and consumption by humans (Parasuraman, 2012).

Agricultural land is defined “as the land area that is either arable, under permanent crops, or under permanent pastures. Arable land includes land under temporary crops such as cereals, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow” (OECD, 2022). China, USA, India, Mexico, South Africa, Ukraine, Turkey, France and Italy have the largest cultivated area for agricultural uses in comparison with other countries in OECD (Figure 1). India has as much cultivated agricultural area as all EU member countries, China has three times that of the EU, and the USA has twice that of the EU. In other words, USA and China dominate with more the 400,000 thousand hectares of cultivated area, followed by India with 179,578 thousand hectares. Other countries with large agricultural cultivated area are Mexico and South Africa with almost 100,000 thousand ha, Ukraine with 41,311 thousand ha, Turkey with 37,797 thousand ha, France with 29,024 thousand ha and Italy with 13,150 thousand ha. Likewise, in 2020, in East Asia and Pacific, 47.3% of land area is agricultural land, in EU is 41%, in Middle East and North Africa is 33.4%, in South Africa is 79.4%, in Latin America & Caribbean is 32.8% and in United States is 44.4% (World Bank, 2020). Only in the Middle East there has been an expansion in the use of land for agricultural purposes, while in other countries there has been a reduction in the percentage of land use for agricultural uses.

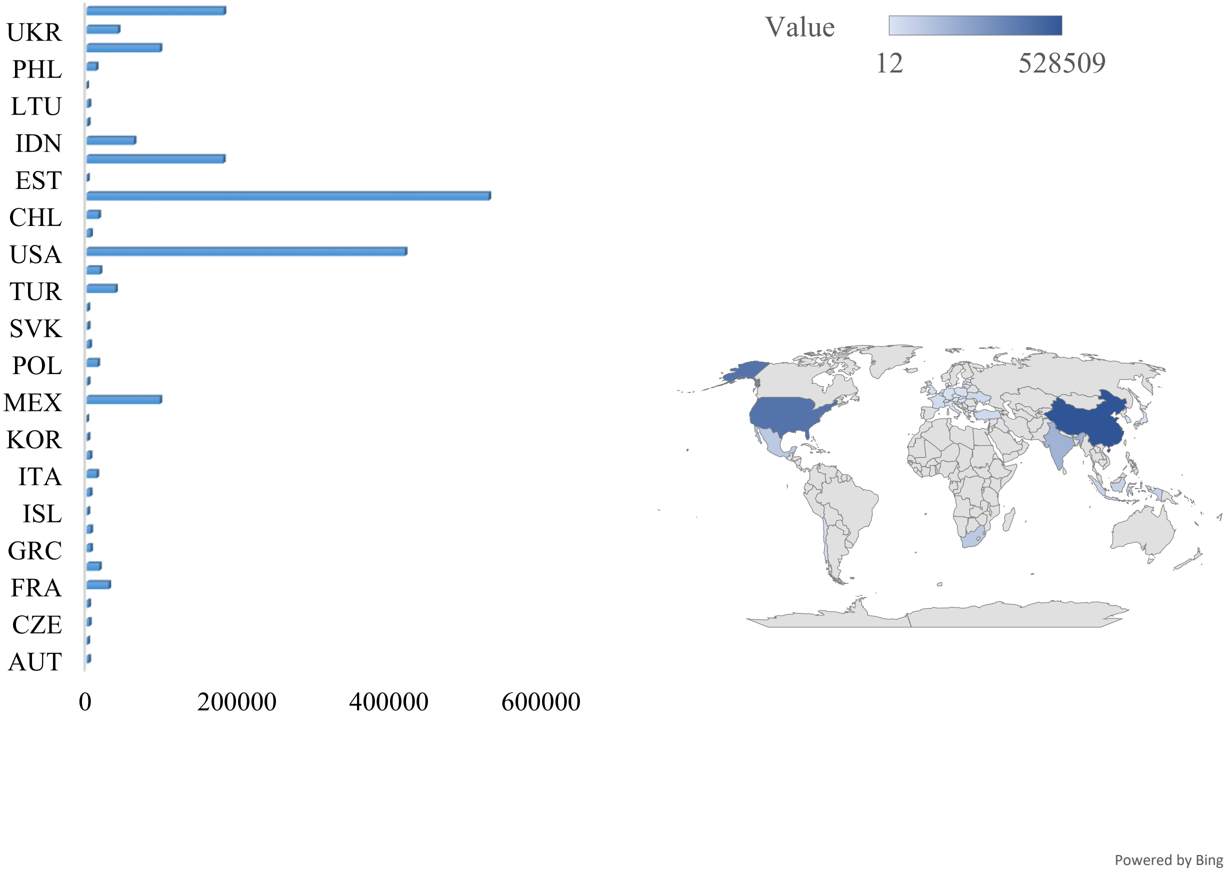


Figure 1. Agricultural land usage by OECD countries.

Source: OECD Data, 2022.

Over 200 years ago, more than 90% of the world's population worked in agriculture where the service sector employs more than 80% of the people in major OECD nations (Hussmann, 2018), and currently there are 39.3% of people working in agriculture (World Bank, 2025). In the last decade, mechanization has been superseded by automatization where mechanization separated production into simple routine tasks which could be learned in a few days where in automatization chip-controlled robots can go through the same motions previously performed by people (Brenner & Brenner-Golomb, 2011). Technological transformation has reformed the workplace constantly over the past two centuries but the speed of automated technologies that are evolving together with the scale at which they could interrupt the world of work, are mostly without criterion (Manyika, 2017). In 1930 Keynes was the first to popularize the term “technological unemployment” but David Ricardo, the father of Economics, from publishing his book “Principles of Political Economy and Taxation” within four years released the new edition “On Machinery” where he changed his mind and claimed that these machineries are injuries (Susskind, 2020). However, (OECD, 2018) reported that since 2011 most regions (60%) have been able to create more jobs at lower risk of automation than those jobs at higher risk of automation.

Moreover, (Gupta & Arora, 2009) have defined automation as “a predetermined sequence of operations with little or no human labor, using specialized equipment and devices that perform and control manufacturing processes, achieved through the use of a variety of devices, sensors, actuators, techniques, and equipment that are capable of observing the manufacturing process, making decisions concerning the changes that need to be made in the operation, and controlling all aspects of it”. Similarly, describes the implementation of technology, software, and programs to accomplish procedural outcome with slight or no human intrusion (Schumacher, et al., 2019). Correspondingly, technology can supplement workers which may result in higher productivity where autopilot technology or statistical software for data analysis are good examples for the technology complementing workers or automation can replace workers fully (WTO, 2017). By using information technologies, agricultural experts will play an important role in crop production and natural resource management (NAP, 1997).

On the other hand, Erik Brynjolfsson and Andrew McAfee, professors at Massachusetts Institute of Technology (MIT) have referred to the latest period of digital age as a ”the second machine age” since these technologies were used also in the past as they had computer software, hardware and networks at their core, but not in a sophisticated and integrated manner as are used nowadays (Schwab, 2017). The word “Digitalization” was used in 1971 published in the North American Review (Schallmo & Williams, 2018a) whereas the term” automation” is originated from the Greek term “automatos” which means self-acting (Guptap & Arora, 2009b). Correspondingly, “Digitalization” and “Digital Transformation” are the main words to enlighten the effect of digital technology on the society as a whole (Larsson & Teigland, 2019). Digitalization defines the social consequences of augmented computer-assistance, new media and communication podiums for the economy, society, culture and working environments (Schumacher, et al., 2019a). Similarly, (Schallmo & Williams, 2018b) have defined digitalization as a fundamental change made to business operations and business models based on newly acquired knowledge gained via value-added digitization initiatives. Consistently, can be combined more easily than other technologies due to the shared numerical basis of various digital devices (OECD, 2020). Likewise, (Csonto, et al., 2019) augmented that digitalization may affect the inflation dynamics as following:

1) The price of goods and services can be influenced by reducing the cost of production and distribution;
2) Through refining the level of productivity, the formation of new higher quality products can affect prices can be affected through the formation of new higher quality products, by refining the level of productivity;
3) The improvement of the flow of information may result in downward shift or the flattening of Philips curve and can also change the creation of inflation prospects.

Artificial Intelligence (AI) is a service robot that executes convenient errands for humans or equipment without industrial automation application where according to its intended application the classification of a robot into industrial robot or service robot is done (Lok, 2019). It has one of its long-term goals the development of machines that can do things as humans can or even better, and to understand this kind of behavior whether it occurs in machines or in humans or other animals (Nilsson, 1998). Likewise, it has beaten human champions in Go and poker, learns chess in few hours, solved a fifty-year old riddle of biology called protein folding, surpassed humans in speech and object recognition, earned passing marks on exams, outperforming in diagnosing lung cancer, powering drones and enabling vehicles (Lee & Qiufan, 2021). On the authority of (Rouhiainen, 2018) agriculture is one of the primary areas where AI can make a substantial impact on the sustainability of resources and quality of life through these technologies such as agricultural drones which can monitor the growth of crops and recognize damaged plants, autonomous tractors which can diminish the workload and gather data about the moisture of soil, and vertical farms powered by AI which help ease food shortages around the world.

AI technologies offer substantial advantages by improving crop cultivation practices, allowing the use of predictive modelling and precision agriculture practices, and supporting efficient crop monitoring and disease identification, and also is more likely to enhance supply chain operations, storage management, transportation systems, and quality assurance procedures (Pandey & Mishra, 2024). Similarly, AI can perform tasks like analyzing the field for crop harvesting, monitoring of crops, and soil conditions, weather forecasting and make predictions for the future, leverage the assistance to the farmers and improve their farming techniques by serving them with correct data (Singh, et al., 2021). In the figure 2 are shown the leading countries who have financed and invested in Artificial Intelligence over the period 2013-2018. China is the largest investor, with total 60% of AI investment followed by United States with 29.1% of AI investment, India with 4.7% of AI investment and other countries with less than 3%.

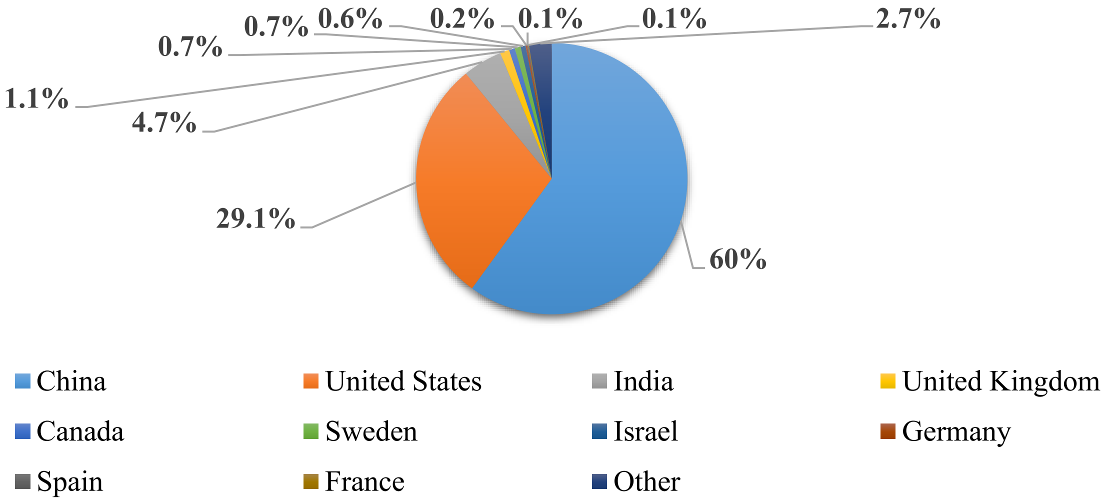


Figure 2. Global Artificial Intelligence (AI) investment and financing by country from 2013-2018.

Source: Statista, 2018.

Figure 3 illustrates the number of industrial robots sold worldwide. The trendline is characterized by an increase and decrease in the number of sales of robots over the years, respectively from 2001 till 2014. The decrease is mostly noted in 2007 while the increase is mostly noted in 2017. However, after 2014 there has been steady growth. In 2001, 78,055 units were sold whereas in 2017, 381,335 units were sold. Hence, the sales of robots increased by 30 %. Similarly, (West, 2018) reported that in 2014 were 1.4 million industrial robots in use and increased to 1.9 million in 2017 where Japan has the greatest number of industrial robots (306,700) followed by North America (237,400), China (182,300), South Korea (175,600), and Germany (175,200).

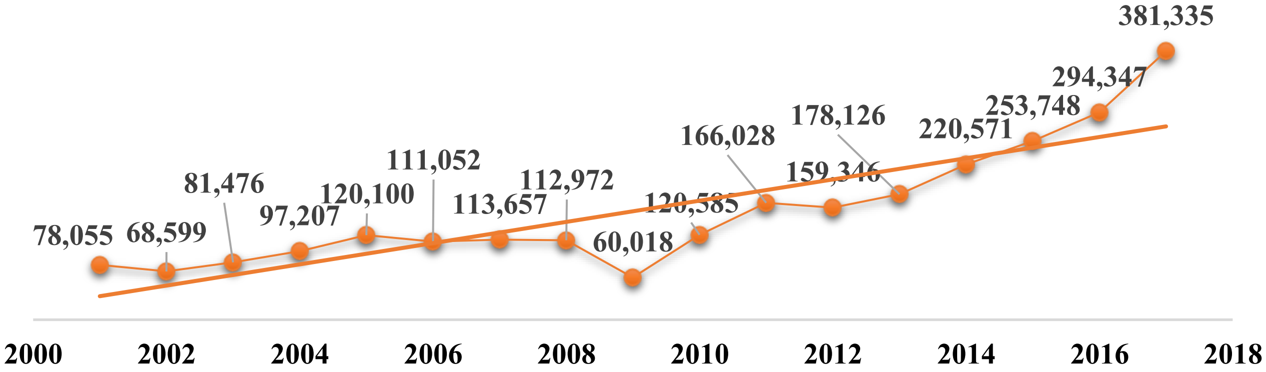


Figure 3. Worldwide annual sales of robots (Thousands of units), 2001-2017.

Source: Own editing based on the OECD data.

Harmoniously, technology plays an important role in the changing patterns of agriculture employment. It has shown vivid results since the 1920s when the mechanical era of technology endorsed farmers to convert from horsepower to mechanical power, and the chemical era from 1950 to 1980 allowing farmers to control pests and disease, till today which has entered into a new era of biotechnology and information technology (OTA, 1985). Modern agriculture, respectively the application of PA technologies is changing the game in agriculture. Precision farming is predicted to facilitate the work of farmers. Simultaneously, chances are high for farmers to obtain financial benefits from the application of precision agriculture, thus agriculture is transforming into a more lucrative industry.

2.2. Theoretical framework of precision agriculture

There are various definitions of precision farming. Precision agriculture was first defined by US House of Representatives in 1997 as a combination of information and production based farming system that is designed to minimize unintentional effects on wildlife and the environment and increase long-term site-specific and whole-farm production efficiency, productivity and profitability (Whelan & Taylor, 2013). Prior to the formalization of the term "precision agriculture" that originated from the USA in the 1980s, ‘Site-Specific-Crop Management’ or Site-Specific Agriculture’ terms were previously used (Oliver, 2013). Precision agriculture was implemented by US agriculture in the 1980s at a slow pace for almost 15 years due to doubt in profitability, lack of information, and farmer attitude at that time (Ahmad & Nabi, 2021). Since the beginning of agriculture, precision agriculture has existed, but its main concerns have not been environmental ones, as shown by Gilbert and Lawes' work, who intended to investigate the advantages of various crop nutrients and crop variants to increase yields (Oliver, 2010).

Precision agriculture 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, et al., 2020). It has gained recognition in the continent of America in countries as USA, Canada, and Australia whereas in Europe, UK was the first country to adopt precision farming closely followed by France, and in Latin America it began in the middle of 1990 leading by Argentina and then later by Brazil (Tendulkar, 2020). Similarly, it 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). Since 1999 the development of precision farming has occurred concurrently with the fast progression and increased accuracy of the Global Navigation Satellite System (GNSS) and has been made possible by the development of sensor technologies (Uzunova & Dunchev, 2019). Its main primary rule is the adjustment of technological operations to the specifics of certain field locations and understanding a field's spatial variability along with using that knowledge to manage crops more precisely are the foundations of precision agriculture (Hallik, et al., 2022). Likewise, the main technologies applied in precision agriculture include remote sensing, Global Positioning Systems (GPS), fertilizer supply based on Geographic Information Systems (GIS), guided instrumentation, computer models, and variable rate nutrient applicators (Krishna, 2016). These technologies may become a necessity for farmers nowadays. Consequently, are needed by the farmers to enable management decisions which are taken and executed in the right time by assessing the variables obtained from the use of various technologies, and also is needed for having crop productivity, for increasing the efficiency of inputs and helps in maximum use of small land unit by farmer (Tendulkar, 2020).

According to (Escola & Kerry, 2021), sensors are used in the first and four stage of precision agriculture cycle which have two functions:

a) Capturing data about the crop and its environment and,

b) Monitoring agricultural machinery or robots which is carrying the sensors themselves.

Adoption of these technologies assists farmers to reduce costs and improve yields resulting in higher profits since farmers are commonly price takers and its challenging for them to get a price different from what is offered in the market (Pedersen & Lind, 2017). Prompt developments have happened in remote sensing in the past twenty years as satellite imagery has enhanced in spatial resolution, aerial hyperspectral imagery has transformed the ability to differentiate multiple crop features (water, pests, nutrients, diseases, etc.), ground-based sensors have been advanced for on-the-go monitoring of crop and soil (Mulla, 2013).

As stated by (Ahmad & Nabi, 2021), precision agriculture has three main components: information (vital to achieve maximum results for parameters such as crop characteristics, soil properties, pests weather and other issues), technology (keep farmers updated, and increase production, productivity and profitability) and management (combines information obtained with available technology into a comprehensive administration system).

Figure 4. Three main components of Precision Agriculture.

Source: Ahmad & Nabi, 2021.

MarketsAndMarkets, a market research company, has conducted a report about precision farming market, the current demand, forecasts, its opportunities, challenges and dynamics. Based on the report, precision farming market is segmented by application, by technology and by offering. Precision market by offering is segmented as hardware, software and services (Figure 5). As a result, offers a variety of systems, devices and systems that are meant to facilitate the farm operations.

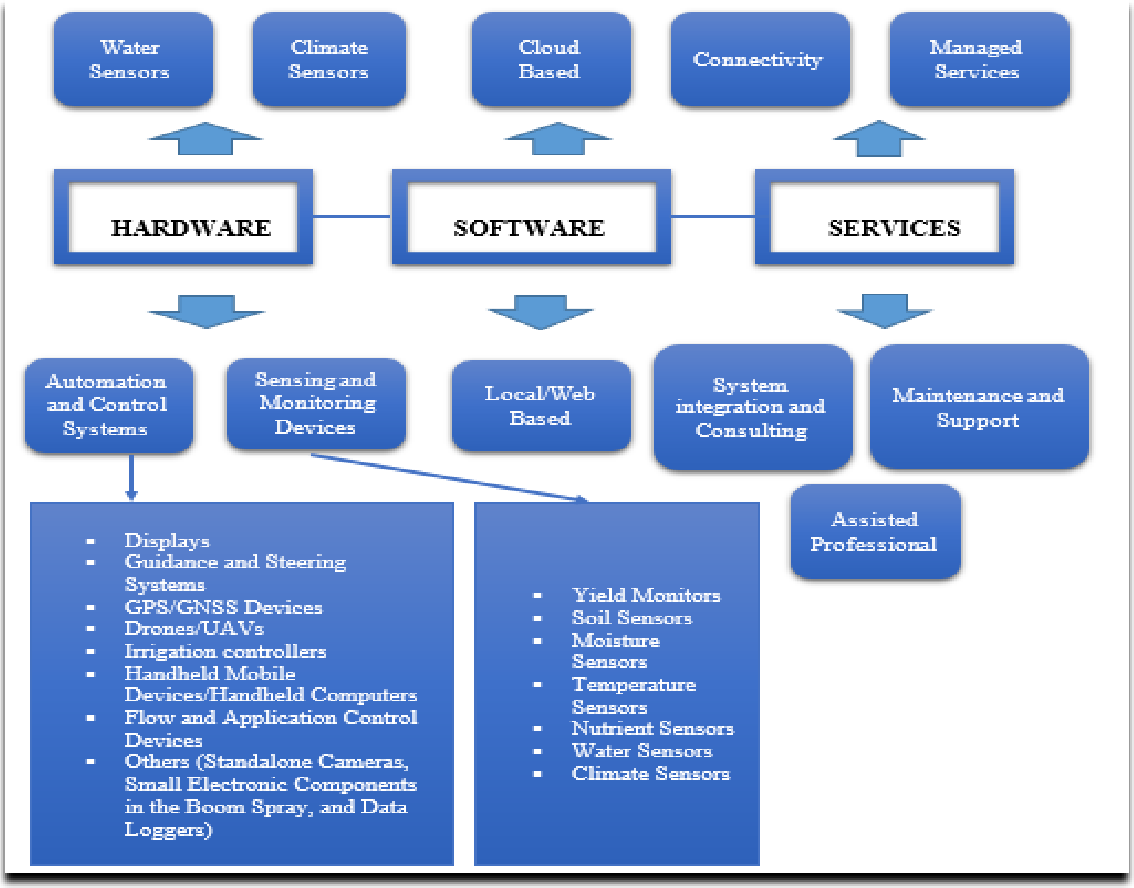


Figure 5. Precision Farming Market, by offering.

Source: Markets and Markets, 2020.

As reported by (Huang & E.Brown, 2019), in the next 10 years precision agriculture will further advance as following:

- Agricultural operation will be led by agricultural automation along with modern materials, mechanical, and electronic science and technology.
- UAV-based plant protection will be updated with the appropriate droplet spectrum, particularly in China.
- The integration of new information systems, remote sensing, and data science will enhance the performance of precision agriculture.

- In order the data to be quickly processed in time for decision-making, precision agricultural plans will integrate data science and big data technologies.
- Japan will develop its own UAV technology for protecting plants.
- To support their own industrial agriculture plans, South America and Africa will try to create and implement UAV.

2.3.Main tools and techniques of precision farming technologies

Crop, soils, land, water, climate, and risk-related studies with data, models, and analytics are some of the major agriculture application areas where geospatial technologies play a crucial role, and also a significant role in agriculture in ways like: easy and prompt data acquisition, near real-time visualization and assessment of natural resources, high-resolution and accurate mapping and assessment, improve yield and productivity of crops, in-season crop damage assessment, improving farm incomes while minimizing risk and more (Mitran, et al., 2020). In terms of precision farming, automation and the application of AI, drones, IoT, robots, and big data are expected to play a key role in numerous aspects of agriculture where utilizing high-performance data-driven scalable learning methods offers better real-time decision-making competences and automates numerous agriculture procedures, transforming conventional farm management into artificial intelligence systems (Bhat & Huang, 2019).

By using remote sensing (RS), geographical information systems (GIS) and global positioning systems (GPS), farmers can more precisely determine what inputs to put exactly where and in what quantities, which would help them to use expensive resources such as fertilizers, pesticides, herbicides, and water more efficiently that would ultimately optimize their yields and boosting their earnings while also cutting their running costs (Andreo, 2013). Spatial mapping and variable rate sprayers work together to apply the exact amount of water and fertilizer needed for any particular area, not only the exact amount, but also exactly what is required for that geographic area to produce high-quality crops, and as a result these emerging tools and technology lower costs, improve crops, boost yields, and more effectively address the problem of feeding a population that is always expanding at a cost that is lower for farmers, the environment, and consumers everywhere (Hamrita, et al., 2020).

In 2016 was a fast development of Global Navigation Satellite System-based technologies including guidance system and automatic section control, and yield monitor on combine harvesters, with adoption rate covering 60 to 80% where the adoption rate is higher in North American farms than in European farms, with an average adoption rate of 17% higher in North America than in Europe, whereas the implementation of technologies connected with variable rate was sluggish with only a third of field crop farms in developed countries to be use within a field (Nowak, 2021). Similarly, (Lowenberg-DeBoer & Erickson, 2019) indicated that Global Navigation Satellite Systems (GNSS) guidance and associated automated technologies like sprayer boom control and planter row have been implemented as fast as any major agricultural technology in history, and the main cause for the perception of a slow adoption of PA is because PA is often related with variable rate technology (VRT) being first adopted by many farmers, but today hardly surpasses 20% of farms. Similarly, modern PA management systems are hardly ever employed on small farms, which consist of much of the world's agricultural production, and where these farms are common in regions of the world that are the least food secure (Erickso & Fausti, 2021).

As stated by (Schueller, 2013), many agricultural automation systems perform these activities:

- Obtain and process information
- Make a decision
- Perform some actions

2.3.1. Global Positioning System (GPS)

In the early 1970s, Global Positioning System (GPS) was first developed by U.S Department of Defense (DoD) for military purposes and then later as a satellite-based system navigation with the aim to provide positioning and timing information (El-Rabbany, 2002). By 1972, the US Air Force and Navy had several years been studying the possibility to improve navigation from space, studies that became the basis for the new synthesis known as NAVSTAR or the GPS (W.Parkinson, 1996). However, in 1983 began the modern age of precision agriculture which is often associated to the statement by US President Ronald Reagan that would allow global positioning systems (GPS) for civilian use (Lowenberg-DeBoer & Erickson, 2019).

Correspondingly, any position on Earth can be found using the satellite-based navigation technology known as GPS which can continually, 24 hours a day, provide three-dimensional, real-time data about positions, navigation, and timing (Mitran, et al., 2020). GPS is a global radio navigation, timing and site system with high precision that works in all weather conditions, employed to gather information about soil, seedlings, diseases, insects and weeds (Sucharitha & Sai, 2022). Within a few centimeters, GPS can pinpoint the precise location at any time of day which could enable highly accurate localization during fieldwork (Uzunova & Dunchev, 2019).

Figure 6. Global Positioning System

Source: Farm Management, 2018.

It is the most important tool in precision agriculture and its benefits range from mapping of soil and crop measurements, application of inputs, monitoring yield and management farm (Ahmad & Nabi, 2021). Likewise, it has an automatic controlling system with light or sound guiding panel (DGPS), antenna and receiver, and GPS satellites transmission signals that allow GPS receivers to compute their position, in other words allowing the farmer to locate the exact position of field information, such as soil type, pest occurrence, weed invasion, water holes, boundaries and obstructions (Ahmad & Mahdi, 2018). The GPS receiver is a remote sensor that collects a wide range of information, such as the location of the equipment, speed, altitude, and other factors, and when georeferencing aids in capturing the location of the equipment being used and transmitting that information to an onboard computer, which then connects it to all other data the computer has gathered at that specific area (Ahmad & Mahdi, 2018). Consistently, helps farmers in soil sampling, crop scouting, mapping the yields, planning, and mapping the field, respectively in conditions which are visibly low and does not hinder the farming process such as dust, rain, fog and darkness (Tendulkar, 2020).

2.3.2. Geographical Information Systems (GIS)

GIS software it is an innovative technology that allows work on data that is connected to a spatially mapped area on the earth and created to work with map data (Ahmad & Nabi, 2021). It is deeply associated to geography since they examine the same characteristics of reality, but GIS is primarily concentrated in computational and interpretation issues while geography seeks to develop and forecast geographical trends (Viana, et al., 2019). Similarly, processes spatial, a-spatial, non-spatial and non-spatial temporal data relating to the objects occur in topography, bathymetry, and space, and applied as a cooperative program for visualization, analysis and computation which consist of spatio-temporal data, and various decision support systems (Panigrahi, 2014).

Figure 7. GIS data being used in precision agriculture.

Source: Cornell College of Agriculture and Life Sciences (CALS), 2017.

As stated by (Steinberg & Steinberg, 2006) requires three general principles which can be accomplished by anyone with a basic computer knowledge:

a) Requires a combination of computer hardware and software tools,
b) Requires data that have a spatial or location component,
c) Requires well-informed individuals to develop the database and implement the data processing.

Consistently, assists farmers to map current and future changes in precipitation, temperature, crop yields and plant health, and can also generate the employment in GPS in line with smart machinery to optimize fertilizer and pesticides application while focusing on certain areas which helps farmers to save money, effort and time as a result (Sucharitha & Sai, 2022). Likewise, a subdivision of information science that deals with geographic data used to gather information, and new models of mobile phones have competences to accomplish GIS tasks, enlarge the reality documented by the handler by getting into databases, and have ability to capture and upload photos (Rocha & Abrantes, 2019).

2.3.3. Remote Sensing

Remote sensing (RS) is the process of gathering data about an object at a distance without making physical contact with it, as well as the collection, processing, and interpretation of that data, and the most popular remote sensing technologies for precision agricultural applications include color, color infrared aerial photography, and videography, which are utilized for a variety of purposes (Belal, et al., 2021). Remote sensing (RS) technologies offer a diagnostic tool that can serve as an early warning system, which before potential problems spread widely and negatively impact crop productivity, allows the agricultural community to intervene early on (Khanal, et al., 2020). Remote sensing techniques can be beneficial for the evaluation of plant health conditions including monitoring and nutritional status, the stress response, plant count pest and diseases identification, yield predictions, (Osco, et al., 2020), disaster location and mapping, wild life management, weather forecasting, water supply information, rangeland management and livestock surveys (Liaghat & Balasundram, 2010).

The work Remote Sensing was first invented by Fisher in 1960AD defined as the art and science of gathering information about objects or areas from a distance without having physical contact with objects area being investigated, and there are several types that are applied in agriculture, but most often used is a passive system that senses the electromagnetic energy reflected from the plants (Jain, 2017). In Yucheng, Shandong province of China, the crop and environment info were acquired instantly with remote sensing and delivered to farmers through a portable information servicing system which was proved effective in improving farmers' production while reducing the negative impacts of farming on the environment that come from over-application of chemicals (Wu, et al., 2010). Using an automatic strawberry flower detection system for yield prediction with minimal labor and time costs, combined with a small unmanned aerial vehicle (UAV) equipped with RGB(red, green, blue) to capture near ground images of two varieties at two different heights, could provide accurate counts of strawberry flowers, which can be used to forecast future yields and build distribution maps to help farmers observe the growth cycle of strawberry fields (Chen, et al., 2018).

As stated by (Jain, 2017) the main advantages are:

- **Synoptic View** – A single image/photo can cover a wide area.
- **Receptivity** – Can get the data of any area repeatedly
- **Coverage** – Inaccessible areas like mountains, swampy areas and thick forests are easily covered.

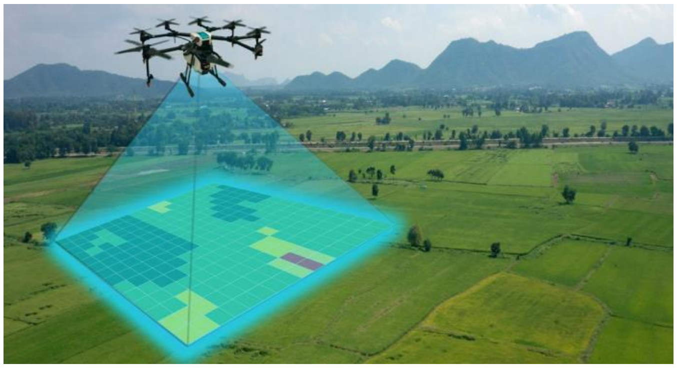


Figure 8. Remote Sensing in agriculture.

Source: INFRAE, 2020,

2.3.4. Variable Rate Application

Agricultural machinery that can apply varied amounts of materials to a field depending on a georeferenced prescription map or real-time data from a sensor is known as variable rate application technology (VRT), and based on spatial data gathered from the field, this technique enables customized application rates of fertilizer, seed, or crop protection agents (Ehsani & Durairaj, 2009). By minimizing overapplication, VRT can reduce inputs while increasing profitability and lowering environmental concerns, and the "original" precision agriculture technology was VRT, but farmers found it difficult to use due to the dearth of simple-to-use tools and the level of expertise needed to produce prescriptions (Rx) maps (Fulton & Darr, 2020).

The term "variable rate technology" (VRT) describes the application of various input quantities (fertilizer, seeds, and chemicals) in various fields (Kumar, et al., 2022). Similarly, with the aid of variable rate technologies (VRT), it is possible to apply seed, insecticide, and fertilizer at various rates as the machinery travels across a field, and although these maps are not easy to make, some farmers are using geographic information systems to track a variety of field and crop parameters in addition to their yield and soil maps (Ebel & Schimmelpfenning, 2011). Variable rate application technology consists of two basic systems: sensor-based systems where real-time sensors can be mounted on the tractor or the front of the implement and map-based systems which depend on having the information about application rates pre-programmed into their memory (Price, 2006). A sensor-based VRT system regulates the quantity of product applied using data from real-time sensors, and these sensors instantly gather information about the soil and/or plant properties, and that information is matched to the kind and quantity of inputs required at that particular spot, and GPS is not required for the execution of this type of application approach whereas a map-based VRT system alter product rate in accordance with an application map that has been produced and stored in a controller's memory (Ehsani & Durairaj, 2009). Correspondingly, the map-based VRT system adjusts the rate of application using a GPS receiver, an electronic map, or a prescription map while the use of real-time sensors as opposed to previously gathered data in map-based VRA is one of the significant benefits of sensor-based VRA (Mani, et al., 2020).

Site-specific management (SSM) of farm inputs is a result of the development of variable-rate technology (VRT), although one of the initial applications of VRT was in fertilization, many farmers are unable to assess the effectiveness of the technology (Fulton, et al., 2007). Variable Rate Fertilization enables the application of various fertilizer dosages, enables the improvement of fertilizer usage efficiency and the reduction of fertilizer leaching, and seeks to increase crop yields while obtaining the best possible cost-benefit ratio, and the first VRF was applied on a farm managed by University of Minnesota in 1993-1994 on an experimental study which indicated that VRF enhanced plant output by roughly 30% (Hallik, et al., 2022).

2.3.5. Wireless Sensor Networks (WSN)

Wireless Sensor Networks (WSN) is a technology in which several sensors are deployed across the field used for humidity, vegetation, temperature, texture, structure, nutrient level, air, etc., with the aim to provide information about various parameters in the field (Ahmad & Nabi, 2021). It consists of many small and inexpensive nodes, where each of nodes consists of a simple processor that is equipped with a wireless transceiver and several states of art sensors (Goh, et al., 2007). Similarly, comprises of three main elements, specifically sensor nodes, gateways, and software where sensor nodes provide data on environmental conditions, then the data is delivered wirelessly through the gateway to be collected, processed, and displayed using the software (Syafarinda, et al., 2018). Wireless Sensor Network is applied in many sectors such as environmental monitoring, natural disaster prediction, home appliances containing many fields like agriculture, and health care, clustered databases and other (Shiravale & Bhagat, 2014). They enable the monitoring of sensor applications in difficult or hazardous environments, which as a result cellular phones, radios, and GPS can all be utilized by wireless networks, and data mining and sensor networks can be merged to map the behavioral forms of various crops (Hamrita, et al., 2020). Consistently, (Shinghal & Srivastava, 2017) stated that using WSN agricultural parameters like depth of water, soil water tension and system capacity are expected to maintain optimal SWT for irrigation management system for better crop yield and increase the application efficiency of irrigation system by 10%.

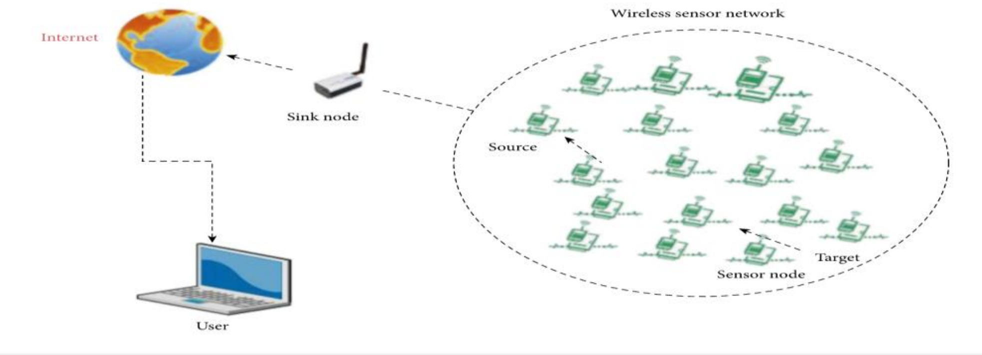


Figure 9. A sample of Wireless Sensor Networks (WSN).

Source: (Malik, et al., 2020).

2.3.6. Sensor applications

2.3.6.1. Yield Monitoring and mapping

Monitoring a field's yield variations across time and space is known as yield monitoring. A yield monitor is a set of hardware and software that creates yield maps by weighing or measuring the harvested crop and fusing that information with GPS latitudinal and longitudinal data (Ehsani & Durairaj, 2009). The monitor, which is located in the cab of the combine or tractor and can store memory and transfer money to a laptop or computer, is also sometimes referred to as a task computer, receiver, or yield monitor, and its main purpose is to display the data gathered by the various onboard sensors so that the operator can see various moisture levels, crop yield, and other information in real-time (Ahmad & Mahdi, 2018). Through the years, the measurement system has transitioned from volume to weight, with yield monitor estimating a flow of the commodity through harvester then merging this information with other sensor data such as GPS and moister to compute yield, but conventionally, crop yield was supervised very indelicately using a volume or weight measurement system like weighed wagon or truckload weighed when the commodity was delivered to the buyer (Fulton, et al., 2020). Similarly, they are either flow or lead cells sensors used to monitor yield during the harvesting operation (Johnston, 2002). Likewise, in combination with Global Positioning System (GPS) technology, yield monitor is an electronic tool that collects data on crop performance for a given year, and also the first step producers take in precision farming which to have accurate data for yield map interpretation, must be properly operated and calibrated (Grisso, et al., 2005).

Figure 10. Yield monitoring in agriculture.

Source: PrecisionAg, 2015.

A computer and some yield map software are needed for a yield mapping system, and common yield map browsing software include programs as Goldstar, Quickyields, JDMap2.1, and AgBrowser (Price, 2006). The practice of gathering georeferenced data on crop yield and attributes, such as moisture content, as the crop is being harvested is referred to as yield mapping, and yield maps are based on a DGPS receiver and sets of immediate yield data points composed with the yield sensor compotes (Ahmad & Mahdi, 2018). Although a yield map is a fantastic informational tool, it is unable to identify the causes of yield variability on its own, and most of the time, it raises more questions than it does, therefore, more spatial soil and plant data are required to interpret the yield map (Ehsani & Durairaj, 2009).

2.3.6.2. Soil Sampling

According to the definition of soil provided by soil science, soil is an autonomous natural body having a distinct morphology from the soil's surface all the way down to its parent material (Tan, 2005). A key component of satellite-guided precision farming is soil sample which immediately affects how accurately computerized soil maps are created, and drawn soil samples must be extremely indicative of the current state since any mistake made during extracting and analyzing soil samples could have cumulative consequences and affect the accuracy of the maps and conclusions we've made for use in precision farming (Krishna, 2016b). A soil profile is made up of numerous horizontal layers, or "soil horizons," that run from the surface down to the parent material, consisting of six primary categories of horizons, referred to as master horizons, the letters O, A, E, B, C, and R serve as their designations which may vary in regard to soil texture, structure, permeability, biological activity, and other characteristics crucial to soil formation, fertility, and crop production (Tan, 1995). There are two important techniques of soil sampling: the grid soil sampling and the random soil sampling. The most crucial technique for precision farming is grid soil sampling divided into configuration cells, or squares, and soil samples are taken from each of these cells consisting of different types of soil samples, including regular systematic points, staggered start points, systematic unaligned points, and random composite cells, whereas the second method is random soil sampling, which gathers soil samples randomly from all points on the grid and places them in the grid's center (Belal, et al., 2021).

2.3.6.3. Weed Control

Applications of precision farming to weed management could be advantageous to agriculture because they provide a chance to reduce chemical and non-chemical inputs into crop production through site-specific weed control and the use of precise application techniques, and the gathering of spatial and temporal data on weed occurrence and distribution made possible by precision agriculture technologies will improve understanding of weed biology needed to develop more effective weed management approaches (Singh, et al., 2013). Due to competition for natural resources, weeds can have an impact on food production in agricultural systems by lowering product quality and productivity, consequently, it is necessary to implement an efficient and long-lasting weed management strategy that harmoniously integrates the various control approaches as cultural, mechanical, and chemical without endangering the entire agrarian environment (Monteiro & Santos, 2022).

The precise detection of the position and the identification of weeds are the main requirement for the control of weeds (Dyshekov, et al., 2020). The automated systems of the future will utilize sensor and computer technologies that classify every plant in the field as either a crop or a weed where once the species of weed has been identified, multiple weed control tools are then applied at micro-rates to individual plants based on their biology and are housed on a single platform, for instance, if the system discovered a weed that was resistant to Roundup, it might be sprayed with an alternative herbicide, chopped off with an onboard cutter, or set on fire, and as a result this technology and similar ones will be able to target various weed-killing tools to certain weeds. (Young, et al., 2013). Similarly, (Nordmeyer, et al., 2005) indicated that simple fluorescence measurements which were taken at two different growth stages: cotyledonous and 8–10 leaves have been demonstrated to be useful for classifying different weed species, demonstrating that weed identification in precision farming may be possible using measurements of chlorophyll fluorescence.

Figure 11. The autonomous robotic weed control.

Source: A I Dyshekov et al, 2020.

2.3.7. Drones and Robots

Drones have already been used in different areas. The first drone was used in military warfare in 1916 which originally were built to counter the enemy Zeppelins in World War I, used by British in the Mediterranean region launched from an aircraft carrier names as “HMS Argus” and used by Germans during the combat in 1944 (Krishna, 2018). They are also called Unmanned Aerial Vehicles (UAVs) and can cover 81 hectares in about 20 minutes (Rose, 2017). Consistently, a series of UAVs called as RP-1, RP-2, RP-3, RP-4 were developed by Walter Righter and Kenneth Case in 1937 (Avtar & Watanabe, 2019). Likewise, an eye in the sky whose power comes from the strength of data processing and analytics that take place after the data is collected, can analyze crop health and soil conditions precisely using infrared, multispectral and hyperspectral sensors (FAO, 2018). Typically, UAVs are employed for picture surveys including mapping weed in coffee crops, identifying anomalies in fertilizing delivery systems, and performing maturity studies, and have also been put into use to analyze soil variability, solve pest issues, find variations in crop ripeness, and measure nocturnal temperatures to prevent frost (Belal, et al., 2021). Depending on the size of the farm, type of cameras/sensors and battery capacity determines the type of drone which can be used for agricultural application, and flight time of a drone (Raj, et al., 2019). For instance, the unmanned aerial vehicle such as DJI Phantom are equipped with hyper-spectral or RGB cameras capturing several field images managed by employing ortho-photos and NDVI maps utilizing photogrammetric techniques and is reasonably priced and can be controlled by beginner pilots (Tendulkar, 2020).

Figure 12. Drone application in agriculture.

Source: Business Insider, 2021.

Same as drones, Robots are being used in different sectors. AI is the most prominent field of Computer Science Engineering attempting to redefine the tasks which are carried out by humans and enabling machine capabilities and makes them to comprehend facts, events, analyze the situation leading to better results than humans (Singh, et al., 2021). Research and developments in agricultural robotics were made since 1980s primarily in Japan, Netherlands and the USA, example of robotic weed control and automated harvesting of tomato (Heravi, et al., 2019). Consistently, (Noguchi, 2013) provided us with an overview of the process in the robot farming system as follows:

1) The robot vehicles receive a command from the control center and through a wireless local area network send information data,
2) robot tractor and robot combine harvester can perform their designated tasks and work with each other,
3) the operator at the control center can analyze the data sent by the robot vehicles in real time and can immediately send the necessary information to the farmers, retailers, producer's cooperation, etc.,
4) using GIS, the operator can monitor the real-time status of the robot vehicles while they are performing their tasks.

2.3.8. Precision irrigation

Precision irrigation is defined as “sustainable management of water resources which involves application of water to the crop at the right time, right amount, right place and right manner thereby helping to manage the field variability of water in turn increasing the crop productivity and water use efficiency along with reduction in energy cost on irrigation” (Shah & Das, 2012). The improvement of irrigation water use efficiency in agriculture can be best achieved by better targeting of water both spatially and temporally to meet the site-specific water requirements of plants more accurately while concurrently improving environmental quality of irrigated cropland (Pierce, 2010). Over the last few years, there have been significant developments that have made precision technology practical in irrigation as well such as: drip irrigation and variable rate irrigation (Dorsey, 2017). In drip irrigation, the system reduces stress on the plant, conserves water and works well with saline water, and in its system the plastic pipes laid on the surface of the ground deliver water to plants drop by drop (Shoji, 1977).

Figure 13. Drip irrigation.

Source: Drip Works, 2020.

Simultaneously, (Perea, et al., 2018) indicated that Variable Rate Irrigation (VRI) is a potentially effective method for irrigation management even in a humid environment to save water and reduce drainage, and also assisted to boost crop yield because of the improvement of control of soil water in the root zone, notably during a dry season. Similarly, VRI is an emerging technology to optimize water and energy consumption, increase crop yields, minimize environmental impacts and can apply irrigation water spatially across a field to meet crop requirements on predefined management zones, taking spatial variability of soil properties and landscape features into account (Yari, 2017).

It allows individual control of each sprinkler in the irrigation system, which offers precision in meeting crop-water needs, allows producers to remove irrigation inputs over the restored wetland acres and to vary application amounts on the rest of the field, applying more or less irrigation water in sections of the field that require differential inputs, and can also be used for precise pesticide and fertilizer application allowing producers to potentially save on non-water input costs (Schoengold & Jones, 2019).

Figure 14. Variable-Rate Irrigation (VRI).

Source: Valley Irrigation.

2.4. Adoption of precision farming technologies

Precision agriculture has shown positive advancements over the past ten years in developed countries as the United States, Germany, the United Kingdom, France, and others which have employed information technology and have evolve precision farming techniques appropriate for their region and farm structure (Khosla, 2010). However, in other countries like Italy still they are facing challenges in adoption of precision farming technologies. The main barriers comprise of the complexity these technologies have in terms of usage, high costs and young farmers feel unprepared to apply these advanced technologies (Masi, et al., 2023), and other challenges like lack of evidence of success among vendor farmers, and inadequate knowledge of overall PF positive outcomes (Blasch, et al., 2022). Addressing these challenges requires targeted interventions, such as providing accessible information and financial support Precision farming market size in 2018 was over $4 billion and is projected to expand at around 15% CAGR from 2019 to 2025 (GM Insights, 2019). Based on the report of (Markets and Markets, 2020), the main factors influencing the growth of precision farming market are as follows:

- Increasing farm mechanization in developing countries;
- Rising labor cost owing to shortage of skilled labor;
- Increasing strain on the global food supply owing to increasing population;
- Substantial cost savings associated with smart farming techniques;
- Government initiatives to adopt modern agricultural techniques.

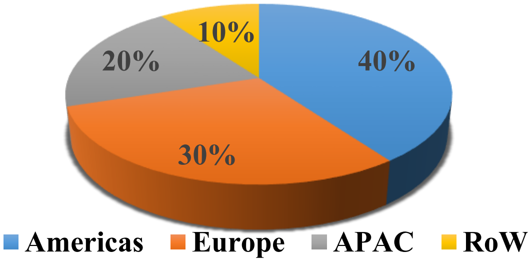


Figure 15. Precision farming market by geography.

Source: Mordor Intelligence, 2019.

Precision farming technologies were utilized on approximately 30 to 50 percent of U.S. corn and soybean acres in 2010-12 (Schimmelpfennig, 2016). America's region is the leading in the adoption of precision farming technologies with around 40% of market share, followed by Europe in the 2nd place by 30%, Asia-Pacific region by 20% and countries in the rest of the world accounting for 10% in total (Figure 15). The early adopters in America's region are considered USA and Canada whereas France, Germany, Spain and UK are the earliest adopters in the Europe region, and China, Australia, India and Japan are the earliest adopters in Asia-Pacific region (Mordor Intelligence, 2019).

According to (Mordor Intelligence, 2020), the market is highly fragmented with various small and medium-sized companies and a few big players, resulting in stiff competition in the market. The major players in offering precision farming tech products are Ag DNA, AGCO, Clear Ag, IBM, and Farmer's Edge which consists of three companies: Fairport Farm software, Fuse Technologies and Granular Ag (Figure 16), and are offering a wide range of products and services as: cloud-based applications, manufacturing machines, environmental predictive solutions, and data drive technologies. Particularly, "Ag DNA" is a cloud-based application and web platform which has brought Internet of Thing (IoT) to agriculture to create agronomic insights automatically from your equipment data empowering farmers to make informed decisions (AgDNA, 2021). AGCO, the world's largest manufacturer of machinery and equipment focused solely on the agricultural industry, offers the best brands on the market (AGCO, 2021). “ClearAg” offers a comprehensive set of evidenced, purpose-built environmental data, models, and tools that distribute actionable results today (DTN, 2021). “IBM” is delivering a global agriculture solution that combines predictive technology with data from The Weather Company, an IBM Business, and IoT data to support farmers around the world with greater insights about planning, plowing, planting, spraying and harvesting (IBM, 2019). “Farmer’s Edge” develops data driven technologies that makes farmers more efficient and productive. Other market research companies such as “Markets and Markets” and “GM Insights” have reported the same results featuring these companies and few more as major players in the market.

Other companies that are offering precision farming products and services are also Agribotix, CropMetrics LLC, Deere and Company, Monsanto Company, Raven Industries, and more others. Ukraine is at a beginner state of adopting PA technologies with very low level of adoption except for GNSS, however many big farming companies offer PA services as drones, soil mapping, and testing, and Large agricultural businesses, such as Kernel offer services including yield mapping, satellite photos, variable rate technology for fertilizer and seed, and rigorous soil sampling.

Figure 16. Major players in precision farming market.

Source: Mordor Intelligence, 2020.

The precision agriculture adoption has a growing trend in developed countries, mainly in the US while substantial growth is also detected in other developed countries, and in both developed and developing countries, auto guidance is more adopted in the last decade while yield monitoring and variable rate application was more dominant earlier (Say, et al., 2017). Similarly, (Maloku, 2020) indicated in her study that United Kingdom, Denmark and Germany have higher rates of adoption compared with other countries in the EU, but the percentage rate of adoption is higher in the USA in comparison with EU countries where it prevails a diversification of precision agriculture technologies adopted by US farmers whereas in the EU, most research papers reported mainly some level of adoption of yield monitors/mapping and variable rate technologies for applying inputs. Likewise, (Paustian & Theuvsen, 2017) show that predictors with positive influence on the adoption of precision farming are agricultural contractor services such as an additional farming business, 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 whereas having a farm of less than 100 ha resulted to have a negative influence on the adoption of precision farming. In Bulgaria, around 2002 or 2003, the first PA application used was a lightbar displays for fertilizer application, and after 2009, these technologies gained popularity and were widely used where according to the 2016 agricultural census, 2350 large farms, which cover 68% of the agricultural area are using variable rate applications application, soil sampling, Geoscan, and weather monitoring technology, precision planting and precision irrigation (Salam & Raza, 2020).

Moreover, based on the study on the adoption of PAT in Germany stated that the most of the interviewed farmers vacillated to be familiarized with precision farming techniques primarily because of the high costs of the technology, most of the interviewed teachers at vocational and technical schools specified that PF was not yet a subject in courses, and also the interviews with the advisors demonstrate that most of them do not provide any advisory service in the field of PF (Reichardt & Jurgens, 2009). Likewise, Bavarian farmers demonstrate possible adoption rates of 15–20% within the next five years for technologies such as barn robotics, section control, variable-rate applications, and maps from satellite data whilst the most used technology is user-friendly automation solutions that decrease farmers amount of work (Gabriel & Gandorfer, 2022). Similarly, based on using primary information from 971 arable crop growers across five countries: Belgium, Germany, Greece, the Netherlands and the UK (Barnes, et al., 2019) stated in their article that the primary obstacle in EU countries appears to be the high cost of entry which is confirmed as bigger farms were more likely to adopt PATs and more possibly to adopt an information intensive PAT package compared to smaller farms. In Denmark, in 2019, 28% of Danish farms, which occupy 66% of agricultural land, were using PA technologies, respectively, 24% of farms used GNSS guidance, 40% of farms used sprayer section control, 5% of farms, used drones and 2% of farms used drone or satellite images, and 2% of farms used crop sensors (Salam & Raza, 2020).

Simultaneously, other study indicate that operator age and gross farm income were found to be insignificant factors, while larger, more tech experienced producers and those utilizing irrigation are more possibly to adopt a higher number of precision agriculture technologies (Castle, et al., 2016). Likewise, even though in Australia precision agriculture technology has been accessible for more than a decade, one of the primary reasons for low adoption of PA is the unwillingness of farmers to invest thousands of dollars without knowing if the technology will return a profit (Robertson, et al., 2007).

On the other hand, (Balogh, et al., 2021) found that the management of the average farm size in Hungary has the highest willingness to innovate and the second highest level of education among the developed clusters, and undertrained farmers with large farms to be the second most open group, which may result in the partial application of precision farming techniques. On the other hand, in Ukraine, the number of farms involving cooperatives that use precision farming has increased compared to previous years, however, not all of them can properly evaluate the real economic benefits of several technologies and the most useful steps to apply them (Hrynevych, et al., 2022). Likewise, agricultural entrepreneurs in Italy still feel skeptical for adoption of PA technologies due to the difficulty of knowing that the economic benefits of technology applied to agriculture take place generally in the long run and that are not immediate (Finco, et al., 2021).

According to the findings, in Brazil 84% of the farmers who were interviewed employ at least one digital technology in their production system, 95% of farmers said they would like to learn more about new technology to advance the development of agriculture on their holdings but the biggest issue is the price of purchasing machines, equipment, software, and connectivity, while the main reward is the perception of enhanced productivity (Bolfe, et al., 2020). Africa's smart farming has been hampered by the regional development of ICT infrastructure as researchers and other agricultural stakeholders are moving forward with digital agriculture and smart farming in general as a result of the Last Mile Project and other initiatives that connect sub-Saharan Africa to the global internet, and also farmers are open to use any technology that makes their regular business operations simpler which is why mobile money using phones is extremely common and widespread to rural communities in Africa (Fastellini & Schillaci, 2020). In UK, based on a survey with a total of 148,000 respondents conducted by Harper Adams University (HAU) presented that 48% of respondents use map-based variable rate technology VRT fertilizer, 63% use GNSS autosteer, 53% used GNSS sprayer boom control and 15% use optical nitrogen sensors (Salam & Raza, 2020).

Additionally, precision farming faces several disputes in developing countries due to fragmented land area, lack of technical knowledge, and low farm income, and can pose threats to market growth in those regions which can be overcome using cost-effective technologies in precision farming and delivering satisfactory skill training related to its operations (Mordor Intelligence, 2020). Nevertheless, since its initiation, the cost of PA technology has decreased, and if this trend continues, usage is predicted to rise in the future, being supported by the continuing collection of soil, yield, and field data (Jochinke, et al., 2007). Likewise, in countries with plentiful land but labor insufficient, adoption is expected to continue, with rates rising when commodities are expensive and interest rates are low (Swinton & Lowenberg-Deboer, 2001).

2.5. Comparison of precision and conventional technology

Agriculture experienced a massive intensification in the quantity of data available for collection, analysis and usage in order to manage inputs and outcomes of agricultural practices when integration of information technologies into agriculture production commenced since the mid-1980s (NAP, 1997). The frontiers of technologies have constantly accelerated in several industries, including in the agricultural industry, such as protected agriculture, precision agriculture and vertical agriculture, being departed from several conventional agricultural practices (Takeshima & Joshi, 2019). As a native form of farming, conventional crop cultivation is considered as the development of local, social and environmental systems which shows a high level of ecological rationale articulated through the intensive use of local knowledge and natural resources, together with the management of agro-biodiversity in a procedure of expanded agricultural systems (Dahanayake, et al., 2017). On the other hand, precision agriculture is an integrated information and production-based farming system which minimizes the unintended impacts on wildlife and the environment by increasing long term, site-specific and whole-farm production (Whelan & Taylor, 2013).

According to the (Pedersen & Lind, 2017), smart farming technologies are divided into three groups:

- Data acquisition technologies – surveying, mapping, navigation and sensing technologies;
- Data analysis and evaluation technologies – From simple computer-based decision models to complex farm management;
- Precision application technologies – all application technologies, concentrating in variable rate application and guidance technologies.

Precision farming technologies such as GPS systems, yield mapping, smart sensors and auto-steering systems allow the farmer to increase the lucrativeness in the farm and reduce the undesirable environmental effect by yield increase, save nutrients and substitute labor time with effective sensing and decision support systems (Pedersen & Lind, 2017). Similarly, the main adjustment between precision and conventional farming is the implementation of current information technologies to offer, process and analyze multisource data of high spatial and temporal solution for decision making and processes in the management of crop production (NAP, 1997). Moreover, the core activities of precision farming are data collection, processing and variable rate applications of inputs, however, majority of farm managers are not skilled enough to utilize the huge volume of precision agriculture information competently and may experience several difficulties on how to explain and perform these data in order to arrive at the execution of decision making on crop management (Fountas & Blackmore, 2005). However, (Lowenberg-DeBoer, 2003) reported that lucrativeness issues have reserved adoption of precision agriculture and also commonly approachability and cost of management time seem to be concerns for adoption of precision farming technology since producers favor convenient technologies which economize on management time compared to those who demand more analysis and decision making.

Correspondingly, (Kogan, 1991) almost three decades ago reported that across the US Corn Belt, which produce 60% of all maize grown in the United States, a functioning maize production model utilizing satellite and climatological data can deliver useful data 1 to 2 months prior to harvest, helping farmers in developing countries from devastating impacts, food shortages famine, and severe droughts in general. Similarly, the capability to evaluate crop production for a region 1 to 2 months earlier to harvest come to be very important, despite of whether a country is a net exporter or importer of crops for food or livestock feed (Hayes & Decker, 1998). Likewise, (Watson, et al., 2003) have estimated the productivity of precision farming and evaluated optimal decision rules of corn production in the Southern High Plains of Texas, and based on their findings, whole-field farming had 7.41% higher yields than precision farming with less inconsistency, and nitrogen fertilizer can be used more competently to boost the net present value revenues (NPVR) under precision farming, hence, precision farming is revealed to be more lucrative than whole-field farming according to the net present value of revenues (NPVR) above nitrogen and water costs. Similarly, (Silva & Murdolelomo, 2008) reported that the productivity of farmers who continued with their conventional practices was lower compared to farmers that applied the new technologies, and the new maize technology did upsurge productivity, where the productivity under new technologies was 3,404 t/ha and under farmer’s practices only 1.737 t/ha.

Consistently, (Ruffo, et al., 2006) conducted experiments on eight commercial production fields by developing a site-specific corn yield production function for VRN fertilization, thus nitrogen fertilizer (NF) necessarily augmented corn yield and cooperated with at least one site-specific variable. Likewise, by allowing enhanced valuation, management, and pointing of precision agricultural practices crossways watersheds, remote sensing tools such as digital aerial imagery and light detection and ranging (LIDAR) can upsurge precision conservation exertions (Delgado, et al., 2011). In this context, variable-rate aerial application delivers a clarification for executing field inputs such as cotton growth regulators, defoliants, and insecticides where several zones of the United States depend on readily accessible agricultural airplanes or helicopters for pest management (Lan, et al., 2010).

On the other side, (Magri, et al., 2005), earlier reported that image data were strictly correlated to both soil organic matter content and drainage patterns, both of which affect yield potential under varied climatic conditions, but showed little correlation with soil fertility indicators and did not assist as good forecasters of field-scale fruitfulness forms, through evaluation of soil test data, bare-soil remote sensing imagery and yield monitor information for their potential contributions to precision management of maize. Other sources show that yield zones ought to primarily exemplify the constant site yield potential and they should be outlined as larger, spatially contiguous areas within a field since spatially varying yield goals are used in several site-specific management recommendations (Ping & Dobermann, 2005).

In recent years, in order to determine whether or not a handheld battery powered D-ATR-FTIR spectrometer is sufficiently precise to be applied as a soil NO3 sensor system to simplify precision N fertilizer management, (Rogovska, et al., 2019) reported that the handheld battery powered D-ATR-FTIR spectrometer with 16 cm phantom resolution is resilient to vibration, high humidity, and temperature immoderations, necessitates no sample preparation and is capable of measuring soil NO3, however in the future, soil NO3 sensing systems may work in combination with big data modeling systems to enhance fertilizer management. Simultaneously, in order to evaluate accuracy of yield and moisture sensing components of forage yield monitors for use in alfalfa/grass and corn silage, (Long, et al., 2016) showed that forage yield monitors with NIR approximation of DM and mass flow estimation for volume can offer detailed and exact measures of DM yield supposing calibrations are conducted frequently, whereas yield monitors may not be accurate enough for determination of yield of small-plots in on-farm research trials or for research but can be used for employing adaptive management and large-scale on-farm prosecutions.

Furthermore, from development of nitrogen instruction program that imitates the penalties of different nitrogen instructions using the decision support system for agro technology transfer (DSSAT) crop growth model, presented a higher profitability in the assorted field in Germany, respectively, hard pan depth, hard pan factor, root distribution factor and the percentage of accessible soil water through the assorted field were suitable indicators in forecasting the magnitude of site-specific plant population benefits over uniform rates (Memic, et al., 2019). The latest movements in precision maize planters indicate that in order to obtain more detailed planting eminence and empower them easier to be used, more and more automation and intelligent technologies are equipped on planters, even though some technologies have been familiarized in developing countries with limited usage due to the dissimilarities of cropping methods, geographical and environmental circumstances, whereas those made in developed countries are modern and advanced (Li, et al., 2016). (Ahmed, 2015) analyzed the adoption of different technologies between maize farmers using plot, household, institutional and infrastructural level information composed from the Central Rift Valley of Ethiopia, using the MVP model. indicated that educational level, family size, off/non activities, livestock ownership, and distance to the market, plot ownership, slop of the plot and other variables also play substantial roles, moderately with contrary signs through technologies, due to the fact that farmers are more likely to adopt a mix of technologies than a single strategy.

Additionally, based on the findings of (Shockley, et al., 2019), for all scenarios autonomous machinery is more lucrative than conventional machinery to determine the break-even investment price for intelligent and autonomous controls. Similarly, precision techniques eliminate differences in soil nutrient availability within a field whereas in conventional farming systems, nutrient recovery rates are adjustable, meaning that nutrient shift from soil to crop phase is more homogenous under precision farming (Krishna, 2016).

2.6. Benefits of using precision farming technologies

As stated by (Paukner, 2022), in the US and Canada the usage of all the precision technologies increased in 2022 compared to 2021, and auto-steer is the most used precision farming technology with 68.5%, followed by field mapping by 56%, and yield monitor data analysis 54.4%. The use of precision farming technologies has a good chance to benefit the economy and the environment of a country which can be confirmed in Denmark. In their study (Jensen, et al., 2012) confirmed that the benefits to the Danish economy of adopting precision farming are optimistic with increased income to farmers and a reduction in fuel consumption and pesticides/herbicides use, and soil fertility increases over time due to reduced traffic increasing yields by implementing new production methods. Likewise, to comprehend the influence of technological innovations in resource poor regions with underprivileged farm households, a study was conducted in Dharmapuri district which showed that adoption of precision farming has led to 80 per cent increase in yield in tomato and 34 per cent in brinjal production (Maheswari, et al., 2008). Other findings showed that profit and environmental benefits were most important reason for adopting PF technologies upon U.S cotton producers, and that educated, experienced, and farmers with farm planning and computers chose PF technologies for profit reasons while younger farmers and farmers using university publication information are more conceivably to signify the importance of environmental quality benefits (P. Paudel, et al., 2020).

(Hrynevych, et al., 2022) specifies the main benefits that Ukrainian cooperative agricultural producers would have from precision farming technologies as:

a) Currently, the level of agrochemical uses and development in Ukraine lags behind that of developed countries by approximately 30–40 years, PF will help reduce the demand for mineral fertilizers and PPP by about 30% and intensify agriculture without significant additional costs.
b) improving economic efficiency by reducing the amount of chemicalization in agriculture which will help decrease soil, summer, atmospheric, hydro- and biosphere pollution overall as a result.
c) having a positive impact on consumer's health because agricultural products become cleaner from chemicals
d) increase awareness about economic and environmental impact in rural areas and will make the work in agricultural sector more attractive.

Moreover, various companies are offering tech products to improve efficiency and productivity in the farm. For instance, the Israeli tech company SupPlant is helping farmers to save water while improving productivity which its AI-powered system analyzes live data from plants, soil and meteorology sensors and translates into irrigation recommendations by using an advanced algorithm (SupPlant, 2022). However, the adoption of these technologies is quite challenging. (Abobatta, 2020) reported that precision agriculture provides different aspects of like: economical aspect to improve the operation system of the farms and field goals, environmental protection goals and social license to farm at risk. There are various factors that affect their spread. Below I have elaborated about benefits from using these technologies.

2.6.1. Economic aspects

Economic sustainability is being encouraged by precision agriculture. Contribution of inputs such as water, fertilizer and pesticides matter significantly to the cost of production as reductions in those inputs and increases in quality production from precision farming technologies can make farming more economically rewarding (Zhang, 2015). More than a decade ago, (Lowenberg-DeBoer, 2003) indicated that the willingness of traditional U.S. producers to undertake the computer analysis and decision making may be a greater constraint than the opportunity cost of the time because producers chose agriculture for the active outdoor lifestyle and are reluctant to spend time in front of a computer.

Moreover, farmers throughout Europe acknowledged similar barriers for the adoption of smart farming technologies such as the cost, the lack of compatibility between devices and an improbable transformation of collected data into usable and accessible information (Knierim, et al., 2018). Likewise, (Larkin, et al., 2015) indicated that farmers with larger farms or higher yields were more likely to believe that they observed positive externalities associated with precision farming technologies, and farmers who found these technologies lucrative or who believed input reduction was important had higher chances whereas those with higher incomes or who were more dependent on farm income were less likely to perceive such benefits.

Nowadays, we have access to numerous literatures which help us to be informed in detail about the economic benefits that a farm has had or will have from the use of these technologies. (Robertson, et al., 2007) indicated in their article that benefits due to reduced overlap of spraying were typically in the order of 10% savings on spraying costs, less fuel use, less soil compaction, less hired labor requirement and more timely sowing whereas intangible benefits were the ability to conduct on-farm trials, increased knowledge of paddock variability, increased confidence in varying fertilizer rates, and better in-crop weed control due to shielded spraying. Likewise, automated technologies such as automated guidance and section control have near-immediate payback and can readily be used by most users, whereas data technologies such as yield monitors, precision soil sampling and variable rate applications require additional skills to use the technology effectively, estimating the payback periods for the data intensive technologies is harder than for automated technologies that reduce fatigue and accelerate seeding as a result (Griffin, et al., 2020).

Furthermore, (R.Gerhards & M.Sökefeld, 2003) when they made a study about a system for site-specific weed control in sugar beet, maize, winter wheat and winter barley using digital image analysis, computer based decision making and GPS controlled patch spraying, showed that it is profitable to invest in these technologies since economic benefits were high in all crop when type and dosage of herbicides were varied according to weed distribution. The findings from alternative spatial nitrogen application studies which were analyzed in economic terms and compared to the costs of precision farming hardware, software and other services for cereal crops in the UK show that the benefits outweigh the associated costs for cereal farms in excess of 80 ha for the lowest price system to 200–300 ha for the more sophisticated systems (Godwin, et al., 2003). Also, (Far & Rezaei-Moghaddam, 2018) showed that the most significant impacts of precision agricultural technologies include the underground and surface waters conservation, the growth of rural areas, increased production, and increased revenue.

2.6.2. Environmental aspects

Environmental sustainability is also being promoted. In a global basis, irrigated agriculture accounts for about four-fifths of global water withdrawals where the leading countries are India and China with about 30 percent and 52 percent of all croplands irrigated (WORLD BANK, 2018). There are competing demands for our limited water and pesticides are applied uniformly in the field which often results in pesticides being released into environment when they are not needed, the promotion of environmental sustainability supports that water and pesticides are applied where and when they are needed as a result (Zhang, 2015). Benefits of precision farming technologies to the environment come from more targeted use of inputs that reduce losses from extra applications and from reduction of losses due to nutrient imbalances, weed escapes, insect damage, and comprise a drop in pesticide resistance development (Bongiovanni & Lowenberg-Deboer, 2004).

Moreover, the importance of environmental quality and length of time using precision farming technologies were not found to affect the probability of perceiving an improvement in environmental quality (Larkin, et al., 2015). On the other hand, based on the data collected from cotton farmers in 12 southern US states (Pandit, et al., 2011) found that farmers who were concerned with environment emphasize precision farming adoption as a reason to improve environmental quality, and also showed that farmers in coastal states such as Alabama, Mississippi, and North Carolina chose environmental benefits as a reason for precision farming technology adoption. Likewise, under PF, (Dar, 2020) reported that nitrogen residues reduced up to 30–50% levels while variable irrigation can reduce up to 25% water usage in an agricultural field.

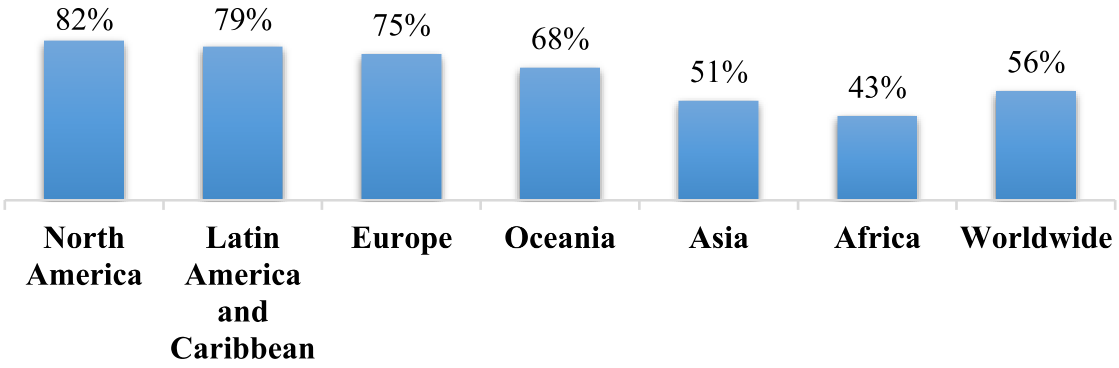
2.6.3. Social aspects

There are already mentioned in various literature sources about the economic and environmental factors that influence the use of precision farming technologies, but not so much about the social aspects that have a high impact in the adoption of these technologies. Therefore, in this subchapter I have provided a brief overview on social aspects that have an impact on the usage of precision farming technologies.

(Vecchio, et al., 2020) found high levels of adoption among younger farmers those that had a high level of education, high intensity of information, with large farm sizes, and high labor intensity. Similarly, (Caffaro & Cavallo, 2019) indicated that low levels of education and working on-farm were negatively connected with the adoption of smart farming technologies whereas farm size had a positive direct outcome on smart farming adoption. Likewise, (Kutter, et al., 2011) evaluated aspects such as forms of communication and co-operation which shows that showed that farm sizes influence the communication and co-operation patterns of agricultural enterprise while large farms employ specialized staff and preferably own their technology, joint investment in site-specific technologies are an option for smaller farms.

Besides, the cloud technology adoption among the young farmers was comparatively higher than among old farmers. Age, high cost, and lack of awareness are the main barriers among non-adopters while lack of allowance, unavailability, ease of use and data ownership are the barriers among adopters (V., et al., 2019). The positive socio-economic utility of precision farming is rated as extremely low proven that the use of precision technologies does not increase local social cohesion, and strong organizational isolation of precision farmers prevents the spread of innovation knowledge and precision farming amongst the farming community (Balogh, et al., 2021). Furthermore, more than half of the world population lives in urban areas compared to rural areas.

Figure 17. Degree of urbanization (percentage of urban population in total population) by continent in 2020.



Source: Statista, 2020.

25.96% of the total world population is directly or indirectly engaged in agriculture while twenty-seven years ago, 43.25% of the total world population was engaged in agriculture, and the total worlds employment in agriculture has decreased for 17.29% where the decrease is more pronounced in middle-income countries accounting for 24.49%, whereas in low-income countries the decrease in employment in agriculture is less pronounced, compared with three decades ago, thus low-income countries have more people employed in agriculture accounting for 67.28% of the total workforce (World Bank, 2018). Similarly, almost a decade ago (Felipe, et al., 2014) reported that from 1962-2013 the employment of Chinese people in agriculture has declined from 83% to 31% where the core drivers for this deterioration were many factors such as an increase in income per capita, foreign direct investment, industrial value-added, etc., which is predicted that the deterioration will reach 24% by 2020.

However, from the current data reported by Statista (Figure 17), North America is the most urbanized continent worldwide with around 82 percent of the population living in urban areas followed by Latin America and the Caribbean which also have a high degree of urbanization with 79 percent, and Europe with 75% of the population living in urban areas. Likewise, (EUROSTAT, 2017) reported that 4.4% of EU population was engaged in agriculture, whereas the highest number of young people in the labor force was stated in Luxemburg (50.0%) and Denmark (44.7%), and the employment of women is more presented in Lithuania and Latvia. Correspondingly, around mid of 2020, the degree of urbanization worldwide was at around 56 percent (Szmigiera, 2020). As a result, migration from rural areas to urban areas has an unfavorable outcome on sociopolitical sustainability, though, the introduction of precision farming technologies may result attractive enough to migrants to encourage them to continue living in rural areas (Zhang, 2015).

2.7. Challenges in the adoption of precision farming technologies in developing countries

Technological, agronomical, and socioeconomic are the main obstacles that prevent implementation of precision farming technologies, where socioeconomic obstacles are costs and a lack of skills, as for agronomical issues are a lack of fundamental knowledge, poor sample and scouting techniques, a lack of suggestions for site-specific fertilizers, information misuse, and a lack of trained agronomic services, and for technology-related obstacles are equipment, sensors, GPS, software, and remote sensing (Robert, 2013).

Despite of challenges as high cost of hardware and software, lack of understanding the technology, lack of inexpensive sensors, lack of awareness about current policies, lack of skills and uneducated background, other challenges that farmers in developing countries face when it comes to the adoption of PA are also the assessment, interpretation and transformation of these data into meaningful management decisions (Mani, et al., 2020). Similarly, (Nguyen, et al., 2022) stated that 63% of studies reported factors at the farm level such as: farm size, resource availability, technology compatibility, social influence, competitive pressure, and government support, and 37% at the individual level such as: observability, trialability, farmer experience, innovativeness, risk tolerance, education, and knowledge.

Still, the future of precision agriculture is promising. In some countries such as US and Europe, some robots are currently in use on small farms, and drones have been made available in Japan for mapping farms and spotting diseases, and there are chances that they will soon be utilized extensively since precision agriculture may benefit small farms by utilizing robots for weed control, crop harvesting as well as sub-surface drip irrigation for targeted water and fertilizer application (T., et al., 2020). Nevertheless, less expensive technology alone cannot ensure greater adoption of various PA technologies because there are many other influencing factors, including how simple the given technology is, the education and skills of the farmers, and the intensity of the enabling conditions as internet access and the adoption process can be sped up with the use of more affordable technologies, organized in a modular way (Mizik, 2023). Likewise, the cost of implementation, particularly as many VRT technologies cannot be converted to older machinery, and the increased level of technical expertise required to operate the equipment are potential obstacles to the implementation of VRT (Fulton & Darr, 2020). Similarly, not all rural areas can easily access high spatial resolution imagery which typically requires contracting and farmers and consultants frequently lack technical expertise in remote sensing and spatial analysis (Guo, 2007).

Correspondingly, (Abobatta, 2020) briefly reported several constraints that limit the adoption of precision farming technologies developing countries as:

1) Farm size because most farms are small scale;
2) Farmers have low socio-economic conditions,
3) Large disparities in education and technology,
4) Significant alteration of cropping system,
5) Lack of market operation,
6) Lack of local technical skills,
7) Lack of data collection and information availability.

Additionally, the collection, processing, and application of data to improve agricultural productivity is fraught with difficulties, and maintaining data security and privacy is one of the key problems that farmers must address if they are to succeed in the information age, whereas other challenges are: available databases and size issue, quality and precision of data, image capture conditions, evaluation measures, and scalability of Data Mining (Shaikh, et al., 2022). Similarly, (Ofori & El-Gayar, 2021) stated that the most frequent challenges raised in social media discourse related to precision agriculture were the cost and complexity of currently available technologies, and the need for proper data security and privacy.

2.8. The state of agriculture in Kosovo

Presently, in Kosovo agriculture contributes 7.4 % to GDP (MAFRD, 2023a). Kosovo's agriculture remains to be characterized by small-scale agriculture, 69% of farms own arable land up to 2 ha, and 46% of arable land is owned by farms with an area of up to 5 ha (MAFRD, 2023b). In 2019, the value of crop production increased by 14% whereas livestock production increased by 8% (MAFRD, 2020), in contrast with previous year which was characterized with a decline in crop production by 3.7% and livestock production by 8.7% (MAFRD, 2019). Currently, the crop output stands at 654 million euros while the output of livestock stands at 315 million euros (Figure 18). The value of crop production increased by approximately 22.93% from 2021 to 2022 whereas the value of livestock production increased by approximately 13.72% from 2021 to 2022.

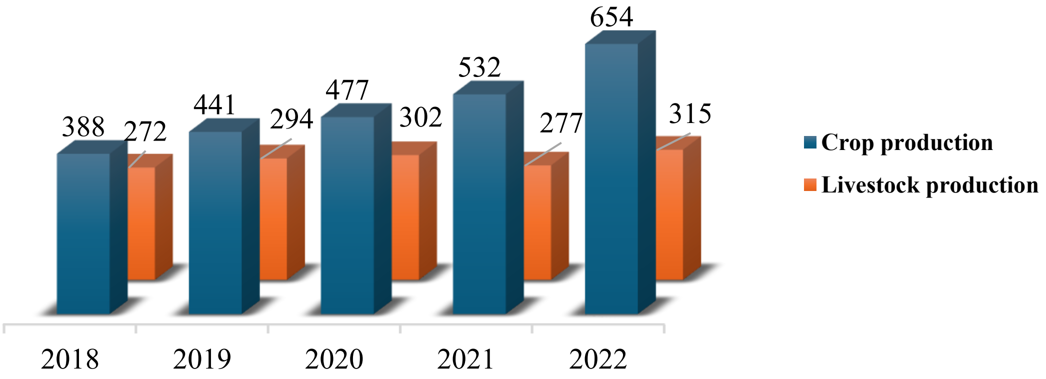


Figure 18. Crop and livestock production in million euros, 2018-2022.

Source: Kosovo Green Report, 2023.

In 2022, the value of crop production was higher compared with previous years, and also in 2022 the value of livestock production was higher compared with previous years.

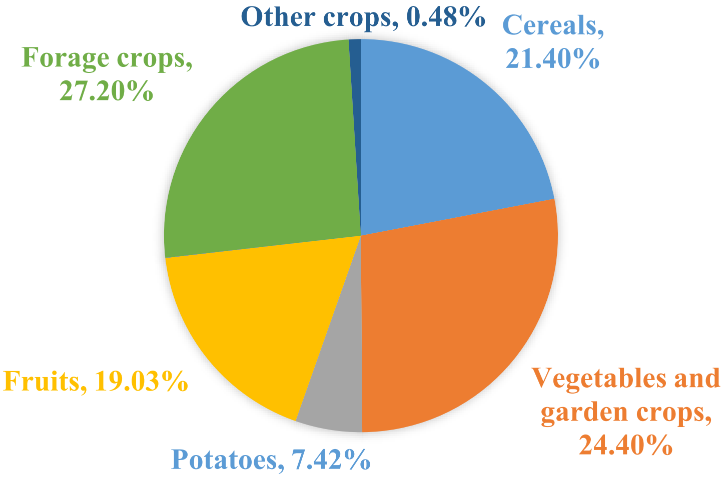


Figure 19. Participation of agricultural crops in total crop production.

Source: Kosovo Green Report, 2023.

In Kosovo the utilized agricultural land area is 420,482 hectares (MAFRD, 2023a) where the largest participation is with vegetables and garden crops by 24.40%, forage crops by 27.20%, cereals by 21.40%, fruits by 19.03%, potatoes by 7.42% and other crops 0.48% (Figure 19). If we compare with the previous years, the participation of agricultural crops is higher compared to previous years.

The largest number of agricultural holdings (30.40%) is of size 0-0.5 ha, followed by the size of 2-5 ha with 23%, size of 1-2 ha with 21.9% and size of 0.5-1 ha with 17.4%. On the other hand, the smallest number of agricultural holdings is of size 30 ha and more, which means that only 0.2% of farms in Kosovo are of that size (Figure 20). The constraints facing Kosovo's agricultural SMEs are lowering their level of competitiveness and keeping them from reaching their full potential for production, where the main obstacles are low adoption of modern methods and technologies, lack of funds, a low input utilization rate, and a restricted capacity to comply with global requirements for food safety (Gjokaj, et al., 2021).

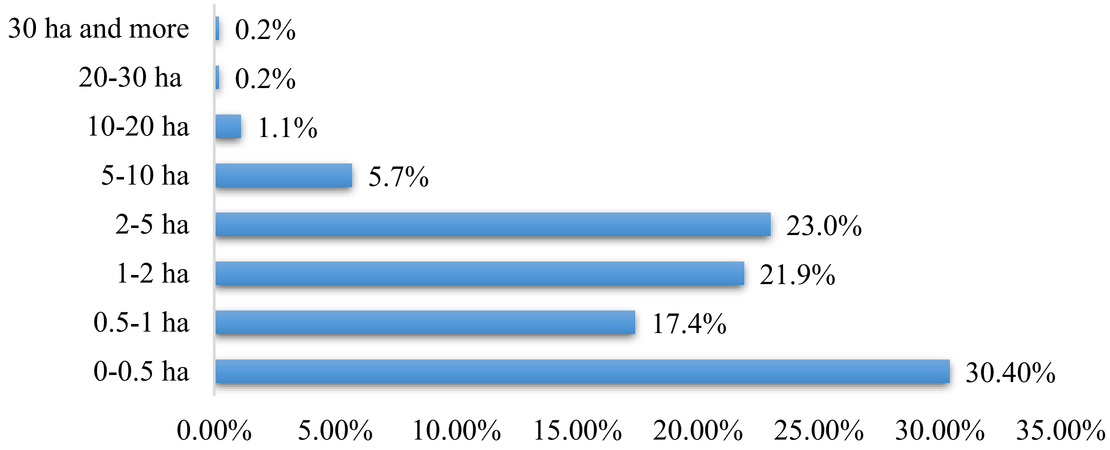


Figure 20. Number of agricultural holdings by farm size.

Source: Kosovo Green Report, 2020.

According to the Kosovo Agency of Statistics (Figure 21), in 2020, 124,741 ha of cereals were cultivated in Kosovo, 542 ha more compared to the previous year, which based on Kosovo Green Report were cultivated 124,199 ha of cereals. Wheat culture leads from the total area with cereals with 80,473 ha cultivated followed by corn with 39,684 ha cultivated (ASK, 2020). Oats are the most widely grown cereal crop after wheat and corn, with an average area of 2,051 ha, followed by barley with a roughly equal area of 1,737 ha, rye (402 ha), and other cereals on a much lower scale than wheat and corn (116 ha) (MAFRD, 2022). Compared to previous year, there was an increase in cultivation of wheat and corn where in 2019, 80,273 ha of wheat were cultivated, and 39,441 ha of corn were cultivated (MAFRD, 2020).

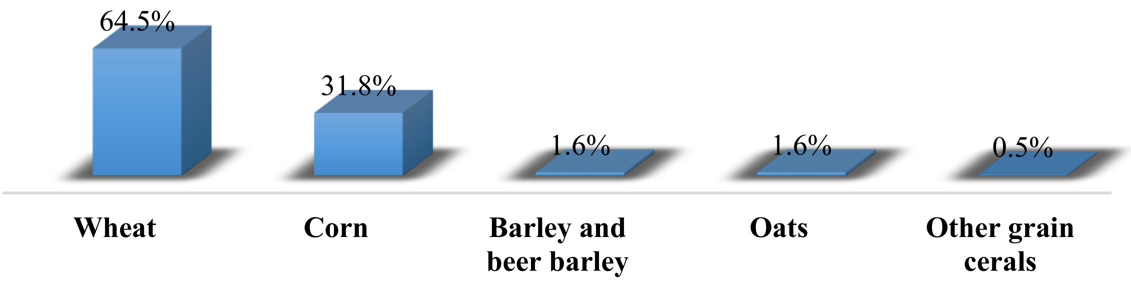


Figure 21. Structure of cereal surfaces per grain.

Source: Kosovo Agency of Statistics, 2020.

Regarding of all agricultural products, in 2018 the country from which it was imported the most is Serbia, which had a value of 150 mil. €, followed by Germany and Turkey with an import value of 49.9 million. € and 49.6 mil. € respectively, Poland 47.9 mil. €, Brazil 46.7 mil. €, Macedonia 45.4 million. € and Italy 40.1 million€, whereas most of the domestic products were exported in Albania (21.3 Mill. €), Macedonia (8 Mil. €), Serbia (6.3 Mil. €), Bosnia and Herzegovina (1.6 Mil. €) and Macedonia (1.6 Mil. €) (MAFRD, 2019).

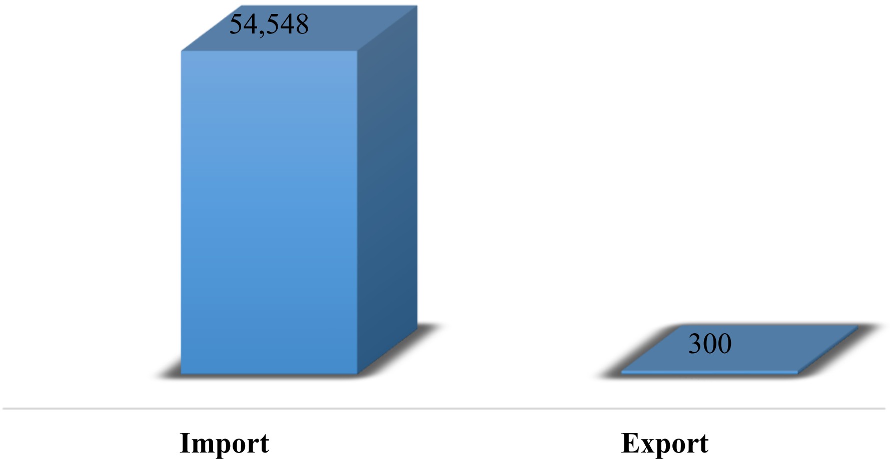


Figure 22. Import and Export of Cereals in Kosovo in 2022 (€'000).

Source: Kosovo Green Report, 2023.

Total export of agricultural products in 2022 was €118.9 mil., which signifies an increase of 28% in comparison to the year 2021 whereas the total import of agricultural products in 2022 amounted to about €1.2 billion, which represents an increase of 24% compared to 2021, resulting in a negative trade balance (MAFRD, 2023a). In 2022, the value of export and import of cereals reached €54,848,000 (Figure 22). In 2020, 52.7% of exported agricultural products took place in CEFTA countries, 39.5% in EU countries and the remaining 7.8% in other countries whereas most of the imported products or 53.7% are from EU countries, followed by CEFTA countries with 24.0% and other countries with 22.3% (MBPZHR, 2021). The value of imported wheat and corn in 2017 was €16.4 million, peaking at 24.1 million euros in 2019 and 23.5 million euros in 2020, with a downward trend in 2021 that is observed when compared to the value of 2020, a decrease of 16.5%, whereas the export of cereals was very small, and primarily wheat and corn seeds were exported, which on average over the course of five years (2017–2021), wheat seed worth €107.8

thousand was exported (MAFRD, 2022). The main country which Kosovo is dependent on import of cereals is Serbia, where Kosovo imported overall €31.6-million worth of cereals, of which 83% came from Serbia (GAP, 2019).

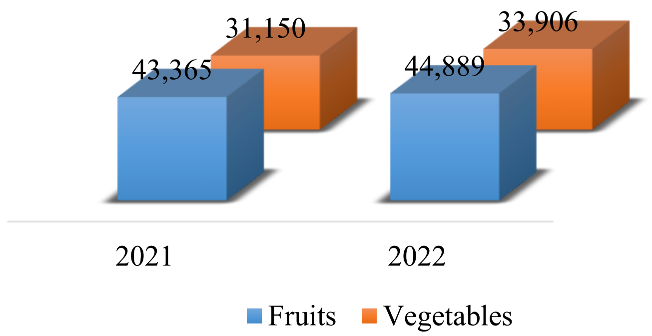


Figure 23. Imports of fruits and vegetables (€'000).

Source: Kosovo Green Report, 2023.

Both fruit and vegetable imports increased from 2021 to 2022. Fruits grew from €43.4 mill to €44.9 mill in 2022, an increase of about 3.5% whereas vegetables grew from €31.2 mill to €33.9 mill, an increase of about 8.8% (Figure 23). Overall, Kosovo depends heavily on imports of both categories, with fruits steadily higher in value than vegetables.

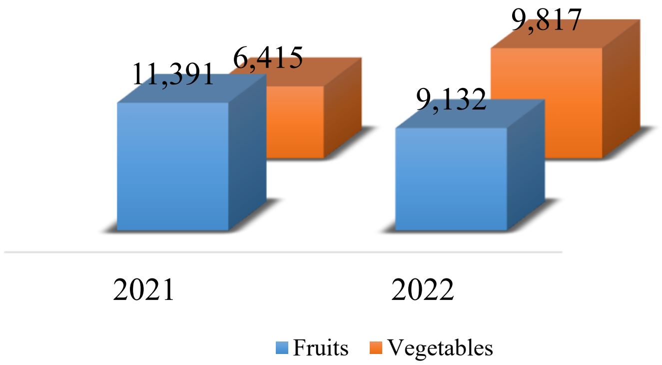


Figure 24. Exports of Fruits and Vegetables (€'000).

Source: Kosovo Green Report, 2023.

Exports of fruits decreased from €11.4m (2021) to €9.1m (2022), a drop of about 19.8%, whereas exports of vegetables increased from €6.4m (2021) to €9.8m (2022), a growth of about 53%. (Figure 24). In 2021, fruits were the dominant export product but by 2022, vegetables overtook fruits, and Kosovo exported more vegetables than fruits.

The area with fruits in Kosovo for the year 2021 marks 10,382 ha, compared to the year 2020 where the area was 10,265 ha where a small increase of 1.1% is observed, whereas vegetable production is estimated to be 282,734 tons per the total area of 19,399 ha, compared to 2020, there is a decrease in production for 2.7% (MAFRD, 2022a). Apples (37,381 tons), plums (11,247 tons), raspberries (5,840 tons), pears (4,953 tons), and walnuts (2,108 tons) were among the crops with the highest production levels in 2021 (Figure 25).

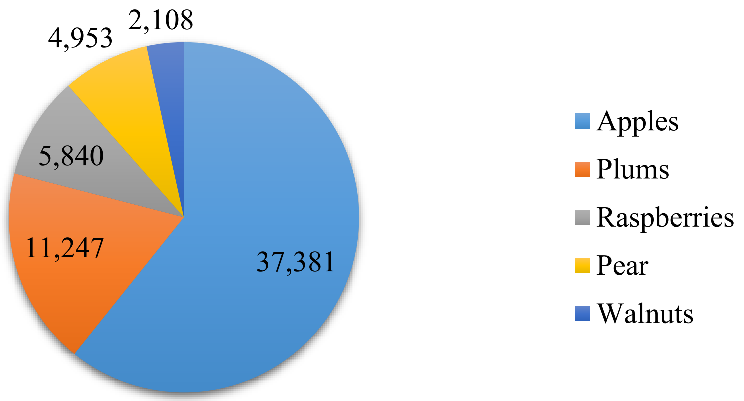


Figure 25. Fruits that have marked high amounts of production in Kosovo (in tons).

Source: Green Report, 2022.

Potato (3,854 ha), pepper (3,146 ha), pumpkin (2,612 ha), beans (2,914 ha), onion (1,369 ha), watermelon (1,309 ha), cabbage (923 ha), maize squash (918 ha), tomato (800 ha), melon (321 ha), and cucumber (305 ha) make up most of the Kosovo’s vegetable cultivated area (Figure 26).

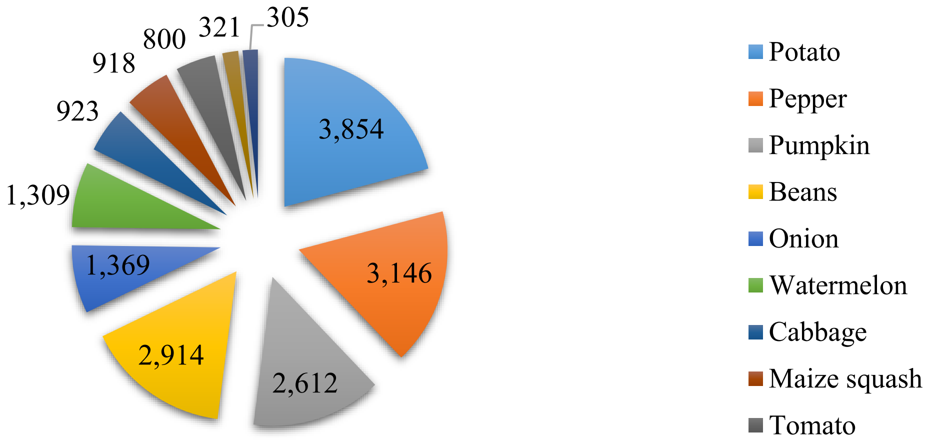


Figure 26. The main vegetables cultivated in Kosovo (in ha).

Source: Kosovo Green Report, 2022.

Simultaneously, Kosovo has favorable conditions for the development of agriculture. It is characterized by fertile soil, sufficient water, and continental climate. Nevertheless, Kosovo is characterized by small scale farms and low productivity. Consequently, small scale producers are constrained by poor market access and do not have strong institutions and skills, knowledge, and convenient technologies (Sonaiya & Swan, 2004).

The agriculture sector faces many challenges. Lack of collaboration in the public and private sectors generally about the agricultural industry and agriculture itself is also a key cause for concern which networks for such collaboration are either nonexistent or underutilized (Gjokaj, et al., 2017). Similarly, (Muriqi, et al., 2019) indicated that due to the lack of trust in the cooperative institutions the level of cooperation among farmers in Kosovo is low and the farmers who live in rural areas, who are young and have got a higher level of education and trust, show a higher level of activity connected with cooperation, whereas farms run by (older) men with lower level of education are less likely to collaborate.

Furthermore, due to financial constraints, farmers lack access to modern irrigation systems where the majority of farms use the sprinkler system and a tiny percentage of farmers can afford other systems, productivity and output quality are continually hampered by inadequate technologies which using outdated vehicles that are insufficient for the required cultivation, and most farmers did not have access to formal education in agriculture, a knowledge that stem from traditions that have been passed from one generation to next (Sahatqija, et al., 2020). Likewise, banks with operations in Kosovo have a relatively small part of the agricultural financing market and have shown no interest in promoting agricultural development where only 8% of agriculture is financed by the banking sector (Hajdari, 2020). Similarly, (Gashi, 2019) stated that due to their lack of knowledge of or inability to manage the unique production and market risks faced by agricultural producers, banks view lending in this sector as extremely risky, which results in high interest rates and significant collateral requirements. To support their statements, (MAFRD, 2022a) indicated in their report that the industry that receives the least credit from financial institutions in Kosovo is agriculture, which continues to have limited access to general bank funding with only 2.1% per in 2021 whereas the scenario is different for Microfinance Institutions (MFIs), where the share of agricultural loans is 19.5% for 2021.

Consequently, PA technologies have not been adopted by farmers yet. However, as part of technological advancement, in 2018, a pilot project was launched by IPKO Telecommunications L.L.C, where 16 agrarian stations, equipped with special sensors, were located in different areas of Kosovo, and most of farmers now receive SMS on their phones concerning the agrological conditions for the cultivation of their agricultural crops, time parameters are monitored, disease development and disease forecasting based on the weather data which are collected by the stations and sent every hour through internet (SIM Card) in the Cloud system (IPKO, 2019).

2.9. The state of agriculture in Hungary

Hungary, located in the central of Europe with a total area of 93,012 km², its agriculture is considered as one of the fastest sectors in Europe. Agriculture is an important strategic sector of the Hungarian national economy where 58 % (5.3 million ha) of the territory are under agricultural cultivation and delivers 9.8 million Hungarian consumers high quality, reliable and safe food and has a substantial share in the food supply of other countries (NAK, 2018). In 2018, the output of agriculture was HUF 2,720.3 billion representing an increase of 4.8 percent at constant prices (NAK, 2018) and according to Hungarian Central Statistical Office, in 2019, agriculture made up roughly 2.0% of the EU agricultural output. Likewise, agricultural and food industry is strongly integrated into the European markets, giving opportunities for non-EU based companies to reach a huge market of almost 500 million EU citizens (HIPA, 2016).

The average farm sizes of arable land increased in the past years where in 2023 was 29 hectares on average, 14% larger in comparison to 2020 and 45% larger than in 2013 (KSH, 2023). Hungary's economy ranked 53 globally in terms of GDP (current US dollars), 35 in terms of total exports, 34 in terms of total imports, and 45 in terms of GDP per capita (current US dollars) (OEC, 2021). It exports €8,780 million agricultural products and imports €5,916 million agricultural products (EC, 2019). In 2020, Hungary's agricultural trade balance was favorable for all product categories except for beverages, and agricultural products including grains and cattle accounted for 2.2 billion euros of the 3.2 billion euros trade balance for all agricultural items in the same year (Medve, 2021). In 2021, grains and grain products made up most exported goods (15%), followed by meat and meat products (10%), animal feed (11%), vegetable oils (8%), beverages (8%), oilseeds (5%), dairy products (5%), and vegetables and fruits (5%) while imports were primarily made up of animal feed (9%), confectionary goods (7%), meat products (7%), dairy products (7%), fruits (7%), and tobacco (5%) (ITA, 2022). Hungary's main export partners are Germany (17.4 %), Romania (11.93%), Poland (6.72%), Italy (6.31%) and UK (6.20%) (WITS, 2020). Around 93% of imported agricultural goods come from EU member countries. Germany (20.4%), Poland (12.8%), Slovakia (9.2%), Austria (7.5%), the Netherlands (6.9%), the Czech Republic (5.9%), and Italy (5.6%) are Hungary's top trading partners (PSF, 2023).

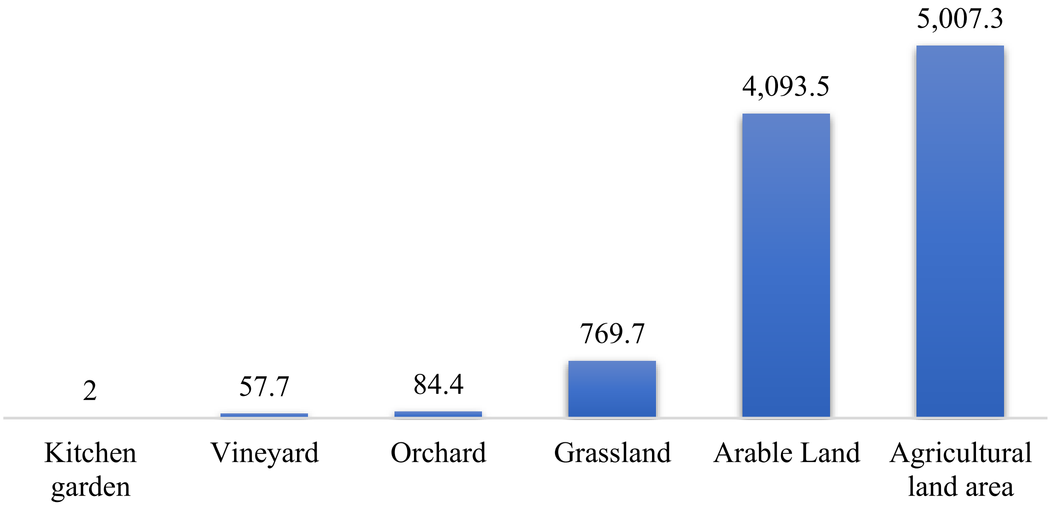


Figure 27. Agricultural land by land use categories, in thousand hectares.

Source: Hungarian Central Statistical Office (KSH), 2025.

Hungary's total agricultural land has gradually decreased over time where in 1913, total agricultural land was about 7.57 million hectares and by 2025, it fell to 5.0 million hectares (KSH, 2025). The total land area used in agriculture is 5,007.3 million hectares. The largest part of agricultural land is used for arable land with 4,093.5 million ha, 769.7 thousand ha for grassland, 84.4 thousand ha for orchard, 57.7 thousand ha for vineyard and 2 thousand ha for kitchen garden (Figure 27).

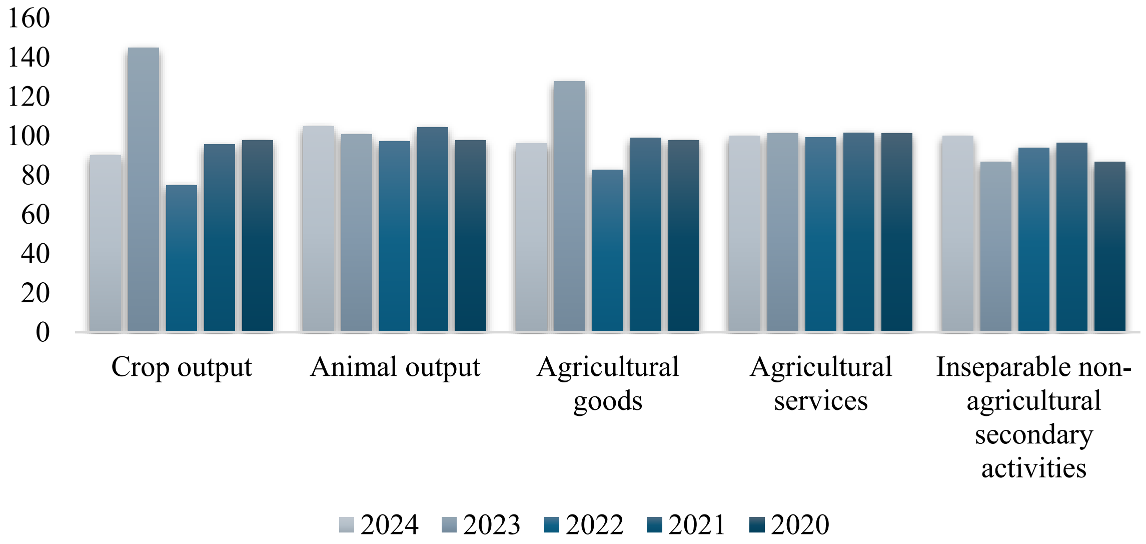


Figure 28. Economic accounts for agriculture, volume indices (percentage of previous year).

Source: Hungarian Central Statistical Office (KSH), 2025.

The data (Figure 28) highpoints the fluctuations in crop output with a decline in production in 2022 to 74.8% but recovered in 2023 to 144.7%, before diminishing again to 90.1% in 2024, whereas the animal output remained far more stable, consistently close to or slightly above 100%, indicating steady production with modest progress in 2021 and 2024. Meanwhile, agricultural services remained just above or at 100% during the period, while inseparable non-agricultural secondary activities remained under 100 in most years. Consistently, the main contributor components are cereals with 27.6%, industrial crops with 15.3% and poultry with 11.5% (EUROSTAT, 2019). The average farm size increased for +35.1 % from 5.6 to 7.6 hectares while the average size of agricultural enterprises decreased for-18.4% from 310 to 210 hectares (Bene, et al., 2016).

The prominence of plant production has increased in Hungary over the last ten years where three quarters of the enterprises grow plants, forty-seven percent of the private farms grow plants, while barely 20% deals with animal breeding and 25% deals with both types of activities, and twenty-six percent of the farms keeps animals, mainly cattle and pig (KSH, 2020).

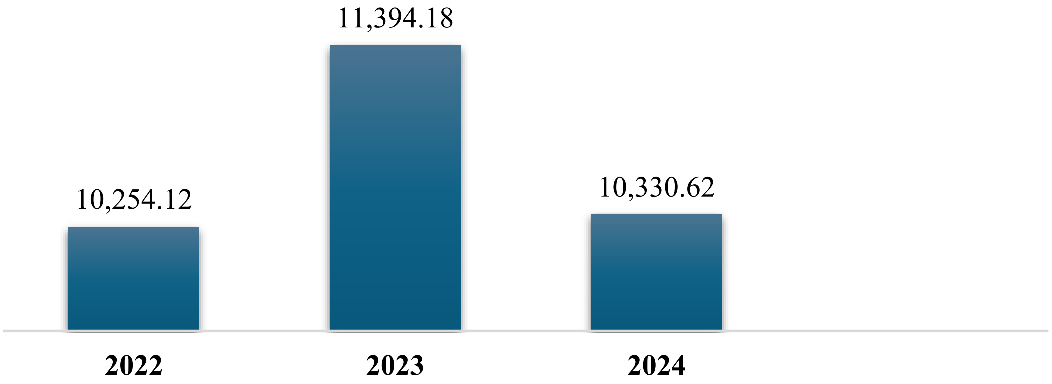


Figure 29. Agriculture output (in million euros).

Source: Statista, 2025.

The total value of agricultural output in Hungary, measured in million euros, for the years 2022, 2023, and 2024, show that 2022 recorded the lowest output, while 2023 experienced a sharp increase, marking the peak of agricultural production during the period, and by 2024, the value had declined compared with the previous year but still remained above the 2021 level (Figure 29). In Hungary, precision farming is still a unknown concept for most people even though has started to be applied in the last and a half decade where according to a survey published in 2015 only half of the crop producers heard about it: 88% of the large scale farms over 500 hectares, 67% of the medium-scale farms between 100 and 500 hectares, while one-third of the small-scale farms less than 100 hectares had heard of precision farming (Katalin, et al., 2017).

Nowadays, as claimed by 2019 eNET's thematic research, awareness of the concept of precision farming is at an average level among Hungarian businesses (individual entrepreneurs and companies) engaged in plant cultivation: 79% have heard about it and know what it means, about 61% of farms are open to adopt precision devices and some 23% claim to be engaged in precision farming (eNET, 2019). Similarly, has first been applied in 2004 characterized with a sluggish growth until 2012, adoption rate was reliant on precision farming technologies and crop type, and precision nutrient management was leading in oil seed rape, winter barley and winter wheat while precision sowing was more dominant in maize and sunflower, according to a study conducted by Hungarian researchers published in the Agricultural Economics journal (Katalin, et al., 2018). Likewise, (Lencsés, et al., 2014) reported that the adoption of precision farming technology depends on the quantity of the cultivated land and the age of the farmers and has mostly been adopted by farms that have more than 300 hectares of cultivated land and by farmers younger than 40 years of age. Several farmers have now started to adopt smaller drones to spray protective substances or fertilizers around their crops and fields, where aviation technology is becoming favored to conventional machineries like tractors since they can conquer difficulties that older technology cannot handle like working in certain weather conditions (Albert, 2024).

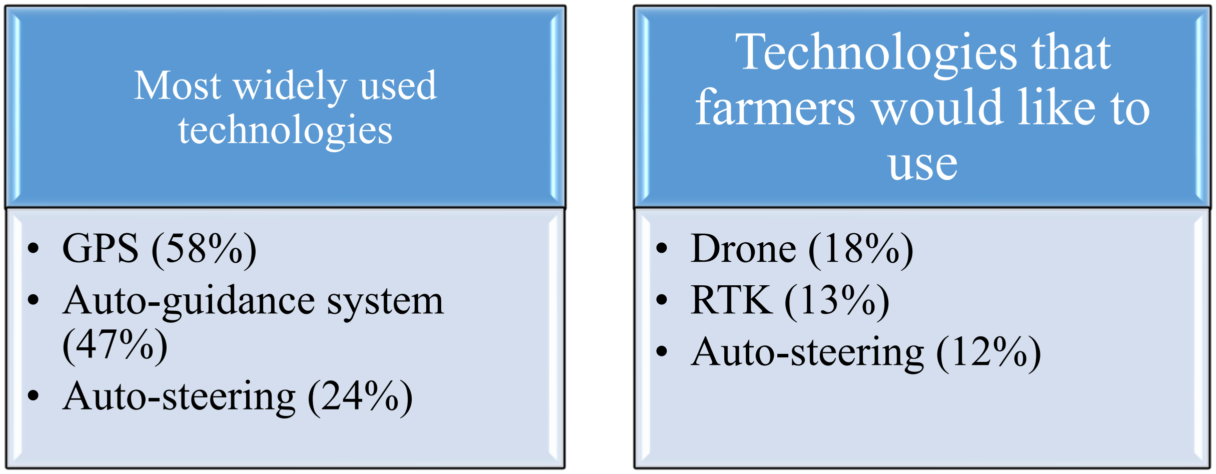


Figure 30. Attitudes of Hungarian farmers toward precision farming technologies.

Source: eNET Internet and Research Consulting Ltd., 2018.

Correspondingly, the alteration between adopted and non-adopted farms is to be noticed, since not all Hungarian farms have started to apply PA technologies due to high investment costs, but subsidies and proper information could cherish it (Katalin, et al., 2018). Similarly, (Balogh, et al., 2020) concludes that the biggest obstacle among Hungarian farmers in adopting precision farming elements is the extra investment costs (38.2%) and the difficulties of application and adaptation (22.7%), in other words it does not fit the size of the farm. Moreover, precision farming is one of the preconditions for the competitiveness of Hungarian agriculture and as a result there are precision agriculture farmers in Hungary who have assembled in an interest protection organization but still exist more than a few causes that prevent the spread of precision farming such as high cost of machineries and equipments, the lack of professional knowledge of farmers, the general lack of trust, the excessive complexity, the unfavorable structure of agriculture (fragmentation of arable lands, aging of farm population), and the frequent changes in agricultural legislation (Fodor, 2020).

3. RESEARCH AND METHODS

3.1. Research design

This study follows a qualitative research design that draws on both primary and secondary data sources. 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. Primary data were collected through 30 semi-structured questionnaires with farmers and experts Kosovo's agricultural sectors, and 30 unstructured interview questionnaires is carried out in Hungary with experts in the field of agriculture and farmers in crop production, based on random sampling, while for secondary data, 31 empirical papers on factors influencing the adoption of precision farming technologies were collected.

The study persists mainly on qualitative data. All data were examined employing qualitative techniques, such as thematic analysis, comparative analysis, and explanatory frameworks such as the Diffusion of Innovation Theory (DOI) and the Mediated Causal Conceptual Framework. These approaches provide a comprehensive, contextualized understanding of how precision farming technologies are perceived, adopted, and consolidated into farming practices. Likewise, no quantitative data were collected or used in analysis, therefore, this research does not apply a mixed-methods approach, but a triangulated qualitative design. Triangulated qualitative design is a technique that qualitative researchers use to for multiple sources and multiple methods for obtaining data on the research topic, and support author's reasoning and alleviates the weaknesses of any one method (Newhart & Patten, 2023). Its main purpose is to improve the process of empirical research by employing multiple approaches to tackle research problems (Cowman, 2008). There are different elements to triangulation as data triangulation, investigator triangulation and method triangulation, and it is generally used in qualitative research to reinforce its reliability (Yeowell & Hartley, 2024). Similarly, triangulation means taking multiple perceptions about the studied topic and the need for it is mostly presented when depend mainly on qualitative data which is broader and richer, and it is important to strengthen the validity of empirical research (Runeson, et al., 2012). Likewise, (Cowman, 2008) claims the same thing in his article that the triangulation is an important feature of its use which has potential to minimize the researcher's personal bias and the validity of findings and can provide insightful research outcome beyond what is possible in the traditional methods of data collection. Also, can be applied in the framework of simple designs in qualitative research which can help plan a case study using a variation of data categories or dissimilar methods or theoretical approaches (Flick, 2018).

3.2. Data collection

3.2.1. Secondary data

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, 2016), and 7ha in Poland (FAO, 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. The chosen studies were reviewed and analyzed thematically, with attention to recurring barriers and drivers of adoption.

Scientific papers deprived of field data, grey literature without peer review and studies concentrating only on non-agricultural technologies were excluded. Likewise, published papers are based on different countries and highlight information such as country, sample, scale, analysis method, type of technologies, variables and sources. Factors were categorized under financial, socio-economical, technical, institutional, and informational dimensions, and patterns were compared across developed and developing country contexts. The eligibility criteria needed studies to tackle the adoption:

- Empirical research centered on the adoption of precision farming techniques
- Reliable data pertaining to developed or developing countries
- Reported in scholarly journals or trusted institutional publications
- Accessible in English language

3.2.2. Primary data

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 questionnaire consisted of both open-ended and closed-ended items, organized into four main sections:

- Descriptive data of the farm like size, type, location, gender, age, education, occupation outside the farm, etc., to get more general descriptive information about sampled farms.
- Awareness of farmers about PATs and use of precision farming tools
- Challenges in adoption and prospects of institutional support
- Prospects and plans for embracing new technologies

On the other hand, an unstructured interview questionnaire is carried out in Hungary with farmers in crop production and agricultural experts, 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, 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 main topics that were covered are:

- Descriptive data as gender, age, location, education, occupation outside farm, farm size, type of production, etc.
- Definitions on precision farming
- Perceptions and knowledge about precision farming techniques
- Experiences with precision technologies
- Benefits and limitations of PAT adoption
- Future outlook in relation with technology incorporation
- Limitations to adoption, arising from financial, technical, and institutional aspects.

The questionnaire comprised open, narrative-style responses and permitted interviewees to give a fuller account on their experiences, perceptions, and attitudes concerning precision farming technologies (PATs). 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.

3.3. Data analysis methods

3.3.1. Theoretical frameworks

To present and analyze outcomes, two main theoretical tools were applied: Mediated Causal Conceptual Framework Model and Diffusion of Innovation Theory.

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).

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. This theory outlines five characteristics that determine people's adoption of new idea as: relative advantage, compatibility, complexity, trialability and observability, and is used to explain how an idea or object is spread and adopted by many different individuals whether it is in an organization or societal context (Mbatha, 2024). 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, 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, 2003).

(Mbatha, 2024) provides clear definitions and meanings to five elements of Rogers:

- *Relative advantage* refers to the degree in which a new product is superior to an existing one.
- *Combability* refers to how consistent innovation is with values, practices, and needs of the latent adopters.
- *Complexity refers to extent to which an innovation is perceived as difficult to comprehend and practice.*
- *Trialability* is defined as the degree to which innovation can be tested or experimented before a decision to adoption is made.
- *Observability* refers to the degree to which innovation provides clear benefits to the users to continue using digital resources.

3.3.2. Thematic Analysis

Data from questionnaire interviews with Hungarian farmers and agricultural experts, and data from the survey responses of Kosovar farmers and agricultural experts were analyzed using thematic analysis. A thematic analysis was conducted to present the perceptions, awareness and future plans on adopting precision farming technologies among farmers in Kosovo and present perceptions and experiences on using PATs among farmers in Hungary. Likewise, explore agricultural experts' perspectives on PATs in both countries. The term 'thematic analysis' refers to a wide range of different sorts of analysis ranging from atheoretical to theoretical, and can be described as merely empirical as the researcher creates the themes simply for what it is in the text (Howitt & Cramer, 2007). Thematic analysis offers a structured yet flexible tactic to finding, examining, and reporting structures or themes inside a dataset and is considered as one of the most broadly used methods for analyzing qualitative data (Ahmed, et al., 2025). Similarly, 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). A theme is a pattern found in the information that at a minimum describes and organizes the possible observations or at maximum interprets aspects of the phenomenon, a code may be a list of themes, and a codebook is the gathering or incorporation of number of codes in a study (Klenke, 2008).

Data from each country was assessed individually, allowing patterns and themes to be compared among the two cases:

- In Kosovo, data was obtained through open-ended questions in a semi-structured questionnaire with farmers and agricultural experts.
- In Hungary, data were collected through unstructured interviews with farmers and agricultural experts.

In Kosovo, main themes encompassed economic constraints, lack of awareness, governmental assistance and reliance on subsidies. On the other hand, in Hungary, main themes were labor skills, digital literacy, workforce skills, institutional guidance and business incentives. Consequently, these themes guided both the descriptive and interpretive analyses presented in the results chapters.

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

3.4. Research ethics

All participants were treated based on accepted ethical standards during the study. Taking part on the survey and interview questionnaire was completely voluntary, with the possibility to withdraw at any time. No sensitive financial or personal data were composed. All data were protected and used only for academic purposes.

4. RESULTS

4.1. 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, et al., 1999), and PAT would be profitable and would improve environmental quality (Watcharaanantapong, et al., 2014). Similarly, (Rizzo, et al., 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).

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, et al., 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, et al., 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, et al., 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.

However, not every developed country is facing a high adoption rate of PATS. For instance, in Italy which continues to stay behind of most other European Union nations in the application of PATs with only 1% of Italy's cultivated land managed by precision farming technologies is having the main problem computerization or how to decode the data since most of farmers who already use this technology face many difficulties in managing such a large amount of data collected by PATs (Bucci, et al., 2019).

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, et al., 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, et al., 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, et al., 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, et al., 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.

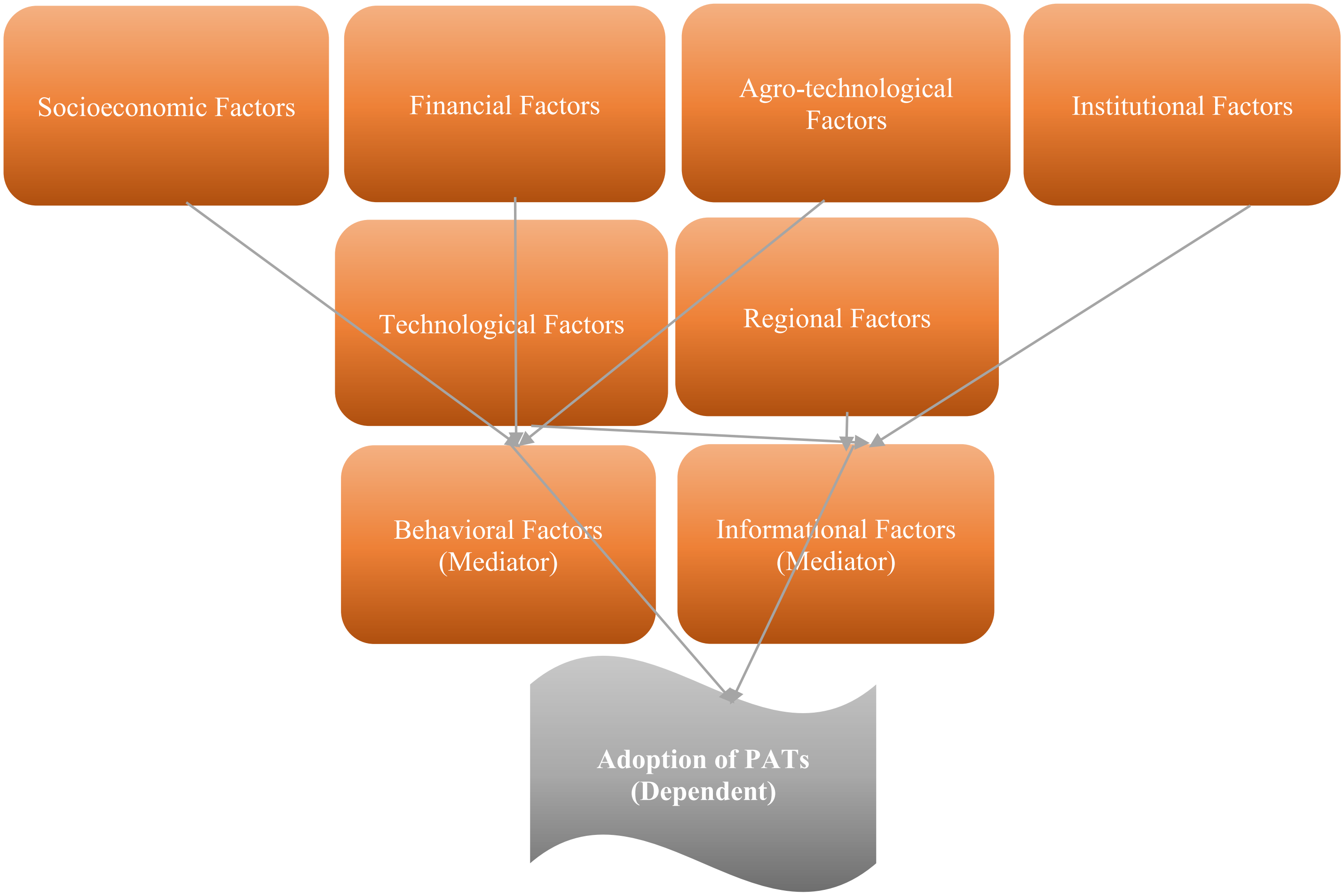
Apart from disparities in income and size, which indicate the financial burden on adoption, there is also a difference in attitude regarding the likelihood of technology uptake due to optimism about its financial return (Barnes, et al., 2019). According to (Far & Rezaei-Moghaddam, 2017), the behavioral 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. Adoption in China, despite the benefits of PA technology for Chinese agriculture lags behind that of several industrialized agricultural countries where farmers' attitudes and views of PA technology influence adoption (Kendall, et al., 2022). (Yatribi, 2020) also mentioned perceived utility as most identified factor in the literature as the determinant of adoption. Personality of farmer (KUŠOVÁ, et al., 2017) and willingness of farmers to trust the technology (Barnes, et al., 2019) can be considered predictor for adoption precision agriculture technologies. Likewise, time requirement and high cost of data handling were cited as the main problems (Tamirat, et al., 2017).

4.1.1. 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 31. 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 consciousnesses 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, et al., 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, et al., 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, et al., 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, et al., 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, et al., 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, et al., 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.

4.2. 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.

Based on the interview with the Engineer of KITE Ltd, the first marked applications of precision farming in Hungary were around 1996-1997. The key player who brought technological innovations into Hungarian agriculture was KITE Ltd., which is one of Hungary's largest agricultural service contributors. In 2010, KITE Ltd. after observing many soil mapping techniques in Germany, made a strategic assessment to fully adopt precision farming by launching a national RTK GPS network in 2011. The nationwide RTK signal network covered nearly all Hungarian arable land with 300 RTK stations. This network of stations allows the basics of precision farming to be established and implemented. Continuously, by 2014, KITE had incorporated GPS-based automation, yield monitoring, and other precision farming technologies. Since most farmers were aging, hesitant to the new and did not have enough IT knowledge, thus, after two years, KITE initiated consulting services to prove farmers and give them positive signals about these technologies. Like so, support farmers' transition from conventional farming to precision farming.

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.

4.2.1. 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).

4.2.2. 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 yeards 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).

4.3. 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.

4.3.1. 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.

4.3.2. 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.

4.4. 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

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.

4.4.1. 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, 2003). Specifically, compare the situation between two countries and highlight the main drivers and barriers in the implementation of PATs.

The adoption of precision farming is still in its early phases in Kosovo. Younger farmers have shown interest in precision farming technologies, but still farmers are facing obstacles such as cost, training, and government assistance. Favorably, with the presentation of funding, knowledge-sharing programs, and technological subsidies, Kosovo could learn from Hungary's precision agricultural accomplishment. Based on the DOI model (Table 5), Kosovo encounters substantial obstacles in terms of funding, education, and trial program access and requires education initiatives, rental-based technology trials, and organized financial regulations to accelerate implementation. Having a well-established RTK GPS infrastructure, sophisticated automated system and government supported consulting services, makes Hungary an innovator in precision farming in Europe.

Precision farming suits well Hungary’s large-scale farming formation, whereas Kosovo’s small farms and traditional methods make integration complex. Likewise, implementation is easier in Hungary by the help of consulting and training programs, whereas farmers in Kosovo face difficulty because they lack digital expertise and capability. Similarly, Hungary permits farmers to try precision farming technologies before investment, while Kosovo farmers lack trial chances, making adoption riskier. Lastly, Kosovo lacks empirical evidence of the advantages of precision farming, while Hungary claims several success stories.

Table 4. Framework analysis: Diffusion of Innovation Theory

DOI ELEMENT	HUNGARY	KOSOVO
RELATIVE ADVANTAGE	- *High* (Time saving, higher production and decreased input usage; Large farms outline substantial profit gains.	- *Low* (Expensive technologies; Struggling with financial resources hampers small farms.)
COMPATIBILITY	-*High* (Corresponding with large-scale farms; Opposition from small farmers who favour conventional practices.)	- *Moderate* (Corresponding with small scale farms; Less with small scale farms which encounter financial and fundamental obstacles.)
COMPLEXITY	- *Moderate* (Farmers encounter challenges in understanding and employing PAT; Due to not enough training, older farmers strive with technological practices and knowledge.)	- *High* (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	- *High* (In cooperation with government and companies, farmers can experiment technologies on small schemes; With the aid of trial projects, larger farms alleviate risk.)	-*Low* (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	- *High* (Success of large farms motivates smaller farmers to adopt; Actual cost and being profitable pushes implementation of PATs between farmers or potential investors.)	- *Low* (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.)

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.

4.4.2. Frequency Analysis

Figure 32. 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.

5. Summary and Conclusions

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, et al., 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.

6. Limitations and future studies

The reliability, scale, and general applicability of any research study can be impacted by restraints. Precision farming is a new management strategy, a new farming approach which makes it quite challenging to find accurate data, facts and statistics. The main purpose of the research is to explore the adoption of PATs in Kosovo and Hungary. This research provides a general comprehension of current situation in Kosovo and Hungary. In other words, to demonstrate where the two countries stand in implementing precision farming technologies. Even though the research study has successfully achieved its objectives and greeted research questions, it has also some limitations to acknowledge.

The main limitation of the research is that it consists of survey responses and interviews, which may not completely stand for all farmers in Hungary and Kosovo. Primary data is generated based on random selection. However, since the size of farms is mainly small among Kosovar farmers and large among Hungarian farmers it may result biased towards specific farm sizes and may not represent all farmer's viewpoints. Although the study presents insights into current adoption patterns, it makes no forecasts about how implementation rates will adjust over the next ten years. The influence of economic swings, upcoming policy changes and climate dynamics on precision farming implementation are not addressed. Moreover**,** farmers' answers are based on their own subjective perceptions and experiences, which can be impacted by personal prejudices. As a result, farmers may exaggerate or underestimate how many precision farming technologies they employ in their farms. Similarly, they may provide answers they think are more suitable and may claim they utilize specific technologies than they actually do. Likewise, the analysis is established on farmers' views. There is no independent scientific proof of the economic and environmental effect from the utilization of precision farming techniques.

Even though this study presents insightful information about the implementation of precision farming in Kosovo and Hungary, it has methodological and contextual limitations that should be tackled in future studies.

6.1. Future studies

The research addresses and presents financial and other barriers but does not provide a comprehensive cost-benefit analysis or any increase in production that comes from precision farming utilization. Although economic sustainability is an important factor in adoption of PATs, it is challenging to determine whether precision farming is a feasible and cost-effective investment for farms of all sizes if they lack practical financial models. To confirm the economic benefits of precision farming technologies, future research should involve direct financial data from farms that are employing these technologies in their farms and conduct financial analysis in order to provide accurate data and serve as a model for farmers who are reluctant to invest in digital technologies.

There are some organized training programs in Hungary while in Kosovo there isn’t any institutional education training program for precision farming. Adoption of precision farming expects dedicated knowledge which is mentioned also in the research study but how adoption rates are affected by training shortages is not addressed. However, the research does not estimate the length and cost of training is needed for a potential in implementation of PATs. Future research should examine the effects of farmer training programs on the adoption of precision farming technologies.

7. Novelty findings and recommendations

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.

7.1. Recommendations

Main recommendations for Hungary:

- **Expand educational training programs for farmers**

  Hungarian farmers especially older farmers have obstacles and lack motivation in adopting precision farming technologies because they do not have expertise and experience in using technology in general. They frequently require advisory assistance due to the difficulty of making the decision to implement precision farming technologies. Hence, developing educational training programs, and other related programs may assist farmers to know how to use and manage precision machinery and understand digital knowledge.

- **Building Local Knowledge and Experience Sharing Associations**

  Based on the interviews with farmers and experts in Hungary, farmers mainly receive reviews about new digital technologies from technology suppliers rather than from real world practitioners. Hence, forming local knowledge and experience sharing associations between adopted farmers and non-adopter farmers is suggested in order farmers to exchange real-world experiences and learn about best practices in managing precision farming devices.

- **Strengthening financial support**

  Even though we mentioned that Hungary has implemented important schemes for developing precision farming technologies. However, small and medium farms still struggle to invest in these technologies since they cannot afford their market prices. Similarly, due to financial constraints high-end equipment is unapproachable for small farms. Therefore, it is recommended to enhance financial support especially for small and medium farmers to try new modern technologies that are suitable for their farm features, for example: small drones.

- **Further Research and Development support**

Further Research and Development support is recommended to help farmers be updated to new technological trends, climate change and other issues that are a concern for their agricultural business. Similarly, it provides an observation of adoption rates, obstacles and opportunities via national periodical national reviews and reports.

Main recommendations for Kosovo:

- **Expanding farm size**

  In Kosovo, the average farm size is small compared to countries who have started to implement precision farming technologies. For example, in Hungary the average farm size is 29 ha compared to Kosovo which is 3 ha. In general speaking, the attitude of farmers toward precision farming technologies differs from farmers who own a small area and farmers who own large area. Farmers who own a 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. Therefore, farmers in Kosovo to be eligible to implement these technologies should invest in expanding their farm size.

- **Developing Government Support Schemes**

  In Hungary, effective schemes for agricultural development is the Rural Development Program which sponsored by the European Union for the purpose to provide grants and loans to Hungarian farmers to support investments, and The Agricultural Credit Guarantee Fund, a financial program initiated by the government to support farmer conquer difficulties they might experience when applying for financial help from commercial banks (Albert, 2024). Different from Hungary, Kosovo does not have a government support scheme for precision farming. Thus, launching government funded initiatives would encourage Kosovar farmers to invest in any precision farming technologies they need to apply to their farm.

- **Establishing a Nationwide RTK GPS Network by private sector**

  In comparison with Hungary which has a well-developed RTK network with 300 stations, Kosovo has a developed RTK network identified as KOPOS a unified state reference network which offers in the real-time positioning accuracy in horizontal plane + 2cm and in vertical plane + 4 cm (Meha, et al., 2014), however is not utilized in agriculture sector which restricts the adoption of precision farming technologies. Therefore, establishing a nationwide RTK GPS network for agricultural purposes would contribute to the development of precision farming in Kosovo, and facilitate decision making of farmers for investment.

- **Implementing training programs**

  As stated by farmers, information and overall knowledge about precision farming is generally gained through self-learning. They do not have formal training programs for precision farming. Hence, it is recommended to implement training centers and consulting services to inform farmers more about everything on precision farming techniques.

- **Promoting Credit Accessibility for potential farmers**

  In Kosovo, in some industries, such as the car industry, financial institutions have taken incentives to provide loans for people who want to invest in new cars. A similar incentive would be beneficial for Kosovar farmers where financial institutions could provide them with loans to invest in new digital machinery. Most farmers do not have enough financial reserves, and precision farming technology is quite costly. Therefore, it is recommended to promote loan accessibility to assist small scale farms buy a precision farming technology based on their needs.

- **Establishing a Consulting Service Company**

  Currently, in Kosovo is not operating any consulting service company like KITE Ltd., in Hungary which is one of the largest agricultural contributors of adoption of precision farming technologies among Hungarian farmers. Subsequently, it is recommended that in Kosovo to be established a similar consulting service company for precision farming technologies and other concerns related to the development of agriculture. Initiation of consulting services would serve as a reliable source for farmers to make the right decision and remove indecision and hesitation to try something new and provide them positive signals about these technologies. Similarly, it would help in incorporating and introducing

GPS-based automation, yield monitoring, and other precision farming technologies in the market.

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LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AI - Artificial Intelligence

AGCO - Agricultural Company

APF - Agricultural Policy Framework

ATR - Attenuated Total Reflection

CAGR - Compound Annual Growth Rate

CALS - College of Agriculture and Life Sciences

DGPS - Differential Global Positioning System

DM - Dry Matter

DNA - Deoxyribonucleic Acid

DOI - Digital Object Identifier

DSSAT - Decision Support System for Agro-Technology Transfer

DV - Dependent Variable

EU - European Union

FACTA - Food, Agriculture, Conservation, and Trade Act

FTIR - Fourier Transform Infrared Spectroscopy

GDP - Gross Domestic Product

GIS - Geographic Information System

GM - Genetically Modified / Global Market

GNSS - Global Navigation Satellite System

GPS - Global Positioning System

HUF - Hungarian Forint

IBM - International Business Machines Corporation

ICT - Information and Communication Technology

IPKO - Internet Provider Kosovo

IT - Information Technology

IV - Independent Variable

KITE - Hungarian Agricultural Machinery and Services Company

LIDAR - Light Detection and Ranging

MAFRD - Ministry of Agriculture, Forestry, and Rural Development

MFIs - Microfinance Institutions

MIT - Massachusetts Institute of Technology

MV - Mean Value

MVP - Marginal Value Product

NAVSTAR - Navigation Satellite Timing and Ranging

NDVI - Normalized Difference Vegetation Index

NF - Nitrogen Fertilization

NIR - Near Infrared

NPVR - Net Present Value Revenues

OECD - Organization for Economic Co-operation and Development

PA - Precision Agriculture

PAT - Precision Agriculture Technology

PATs - Precision Agriculture Technologies

PF - Precision Farming

PFTs - Precision Farming Technologies

PPP - Public-Private Partnership

ROI - Return on Investment

RS - Remote Sensing

RTK - Real-Time Kinematic

SIM - Subscriber Identity Module

SMEs - Small and Medium Enterprises

SMS - Short Message Service

SSM - Site-Specific Management

SWT - Soil Water Tension

UAV/UAVs - Unmanned Aerial Vehicle(s)

UK - United Kingdom

US - United States

USA - United States of America

VRA - Variable Rate Application

VRF - Variable Rate Fertilization

VRI - Variable Rate Irrigation

VRN - Variable Rate Nitrogen

VRT - Variable Rate Technology

WSN - Wireless Sensor Network

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APPENDIX A

Interview Questionnaire with Hungarian farmers and experts

Questions asked:

In Hungarian:

1.Akkor, ha kérhetem, egy picit bemutatkozna nekem? Iskolázottságát tekintve, életkorát, foglalkozástörténetét?

2. Ehhez kapcsolódóan, mekkora terület az amin termelnek.

3. és milyen növények azok amiket termesztenek főként?

4. Az is jó ha tud hozzá egy ha –t is hogy lássuk mi az ami uralkodó jellegű.

5. Tehát akkor szoros a kapcsolat. Ezeket az állattartásból származó termékeket értékesítik-e? Vagy főként a növénytermesztés az ami a fő?

6. Tehát voltaképpen ezek. A megtermelt növények közül mi az, vagyis mindent tudnak értékesíteni, mekkora arányban, vagy van rendszeresen az ami fennmaradó?

7.: Értem, köszönöm Akkor egy picit rátérek, mivel teljes széles körű volt a bemutatás rátérek a precíziós gazdálkodásra. Először is megkérdezném, hogy ön szerint mit jelent, az hogy precíziós gazdálkodás?

8. Kit tart ön, precíziós gazdálkodónak, hogy maradjunk ennél? Mikor gondolja valakiről ismerős ezekben a közegekben, hogy ő már precíziós gazda?

9. Honnan hallott ön először a precíziós gazdálkodásról? Kinek volt a tanács, hogy kezdje el? Beszéltünk a KITE-ről, ők voltak az elsők akik így javasolták?

10. Sokszor akkor azt jelenti plusz kör ha úgy csinálja az ember, mintha úgy csinálja az ember, hogy nem alkalmazza a technikát?

11. Tehát a hozam az nem jelent végül is akkorát ami megérné a befektetést?

12. És ők értik ezt a technikát alapvetően? mondjuk, hogyha van pár ilyen jellegű gép értenek hozzá? Van szaktudásuk? Honnan szerezték meg ezt a tudást az alkalmazottak?

13. Akkor úgy gondolja, hogy az alkalmazottak nagy része képes erre.? Akkor nincs probléma hogy ők hogyan tudják kezelni?

14. Tehát volt egy fluktuáció úgymond?
15. Ezek elsősorban fiatalok voltak, vagy képzettebbek? Mi az ami alapján ez megválogatta őket? Azokat az embereket akiket be lehetett tanítani erre?
16.: és most mekkora az a terült amit művelnek precíziósan, vagy mekkora az amit lehetne? Látva ezeket a talaj különbségeket, minőségbeli különbségeket mennyi az ami belátható lenne, vagy
17. értem, akkor így van-e olyan terület, amit állandóan tudnak, vagy tud most precíziósan művelni? Vagy egyáltalán nincs ilyen? Vagy van, amikor sikerül, vagy van amikor nem?
18. Akkor ezt minden földterületen, gondolom amin lehet, de olyan amin mindent alkalmazzanak olyan nincs?
19. Akkor ennek vannak előnyei amiket használnak?
20. Van olyan, esetleg amit tervez, bővítést, technológiai fejlesztést ebben az ügyben? Van olyan amit már lát , de még költségek nincsenek rá?
21. Végül i akkor az akadálya ez a pénz ugye azt érzem, hogy kellene-e változnia például az állam agrárpolitikájának? Vagy támogatási rendszernek, hogy ezt jobban tudja serkenteni? Van amiben kellene hogy változzon?
22. De voltaképpen azt jelezte, ez is meg fog szűnni, még ez a nem túl jól működő is. Mi lesz a mire a gazdák számíthatnak voltaképpen?
23. Tehát voltaképpen ha jól értem, az fog tudni, és az fog beruházni a precíziós gazdaságba, akinek van egy nagysága, sokkal nagyobb a jövedelem a bevétel , tehát kis gazdaságok nem képesek erre? Ezt hogyan látja, kik vállalkoznak mégis akkor?
24. Tehát akkor van egy olyan belső szűrő, mi az ami jövedelmező. mi az ami megéri, mi az ami kevésbé. És akkor a saját növényeivel és a saját gazdaságán belül van ami nem. Tehát nem lehet az egészre úgy integráltan ráhúzni az egészre különböző gazdaságokra?

In English:

1. So, if I may ask, could you introduce yourself to me a little bit? Regarding your education, age, and professional history?
2. Related to this, how big is the area you produce on?
3. And what kind of plants do you mainly grow?
4. It would also be good if you could tell me in hectare so that we can see what is dominant.

5. So, then the relationship is close. Do you sell these products from animal husbandry? Or is it mainly crop production that is the main thing?
6. So, these. Of the plants you produce, what is it, that is, can you sell everything, in what proportion, or is there something that is regularly left over?
7.: I understand, thank you. Then I will move on a little bit, since the presentation was comprehensive and comprehensive, I will move on to precision farming. First, I would like to ask you what you think precision farming means to you?
8. Who do you consider to be a precision farmer, so that we can stick with it? When do you think someone, you know in these circles is already a precision farmer?
9. Where did you first hear about precision farming? Who advised you to start? We talked about KITE, they were the first to suggest it that way?
10. Often, does it means an extra round if you do it as if you were doing it without using the technique?
11. So, the yield is not what would ultimately be worth the investment?
12. And do they understand this technique in principle? Let's say if they have a few machines of this kind, are they familiar with it? Do they have the expertise? Where did the employees get this knowledge?
13. Then do you think that most of the employees are capable of this? Then there is no problem with how they can handle it?!
14. So, was there a fluctuation, so to speak?
15. Were they primarily young, or more educated? What was the basis for selecting them? The people who could be trained for this?!
16.: And now how big is the area that is cultivated with precision, or how big could it be? Seeing these differences in soil, differences in quality, how much would be foreseeable, or
17. I understand, is there an area that they can constantly, or can cultivate with precision now? Or is there none? Or is there sometimes it succeeds, or sometimes it doesn't?
18. So, this is on all land, I think, where it can be done, but there is no such thing where everything can be applied?
19. So, are there any advantages to this that are used?
20. Is there any, perhaps that you are planning, expansion, technological development in this matter? Is there something that you have already seen, but there are no costs for it yet?

21. Finally, the obstacle is this money, right? I feel that should the state's agricultural policy change, for example? Or the support system, so that it can stimulate this better? Is there anything that should change?
22. But in fact, you indicated that this will also cease, even though this one is not working very well. What will farmers actually expect?
23. So, in fact, if I understand correctly, only those who have a certain size, much higher income, will be able to invest in precision farming, so are small farms not able to do this? How do you see this, who will still undertake it then?
24. So, then there is an internal filter, what is profitable. what is worth it, what is less. And then there is something within your own plants and your own farm that is not. So, you can't just apply it to the whole thing in an integrated way to different farms?

APPENDIX B

Survey questionnaire with Kosovar farmers and experts

Questions asked:

In Albanian:

1.Lokacioni i fermës suaj (Regjioni)?
- ○ Prishtinë
- ○ Gjilan
- ○ Ferizaj
- ○ Mitrovicë
- ○ Pejë
- ○ Gjakove
- ○ Prizren

2.Gjinia juaj?
- ○ F
- ○ M

3. Mosha juaj?
- ○ 18-30 vjeç
- ○ 30-40 vjeç
- ○ mbi 60 vjeç

4. Niveli më i lartë i arsimit që keni përfunduar?
- ○ Shkolla fillore
- ○ Shkolla e mesme profesionale ose Gjimnazi
- ○ Fakultet
- ○ Master
- ○ Doktorature
- ○ Kurs professional
- ○ Pa kualifikim

5. Statusi I punësimit jashtë fermës?
- ○ Student/e
- ○ I/e punesuar
- ○ I/e papune
- ○ Pensionist/e

6. Permasa e fermës suaj?

____

7. Në cilin vit u themelua ferma juaj?
  - 2000-2010
  - 2010-2015
  - 2015-2022

8. Toka është ?
  - Me qira
  - Ne pronesi

9. Lloji i fermës?
  - E vogel
  - E mesme
  - E madhe

10. Cili është sektori kryesor i veprimtarisë në fermën e juaj? (Përgjigje të shumta janë të mundshme).
  - Lavertaria
  - Vreshtaria
  - Pemetaria
  - Perimtaria

11. Ju lutem, specifikoni llojin e kulturës bujqësore që e kultivoni në fermën e juaj?

____

12. Numri i punonjësve ne fermën e juaj?

____

13. Llojet e pajisjeve makinerike apo teknologjike që i përdorni në fermën e juaj?

____

14. A keni të ardhura jashtë fermës?
  - Po
  - Jo

15. A i ndiqni tendencat e reja teknologjike në bujqësi?
  - Po
  - Jo

16. A keni dëgjuar më parë për bujqësinë precize?
  - Po
  - Jo

17. Nëse po, cili është burimi i informacionit?
  - Internet
  - TV

- Radio
- Shoqerise
- Gazete
- Panair
- Shoqatave bujqesore
- Kolegeve

18. A e dini se çfarë është bujqësia precise?

- Po
- Jo

19. Cilën nga këto teknologji të bujqësisë precize keni njohuri apo keni ndegjuar së fundmi? (Përgjigje të shumta janë të mundshme).

- Monitorimi i rendimentit dhe teknologjitë e hartës
- Sistemi i pozicionimit satelitor (GPS)
- Teknologjitë e sensorit në distance
- Sistemet e Informacionit Gjeografik (GIS)
- Teknologjitë e drejtimit të automobilave
- Teknologjitë me normë të ndryshueshme për aplikimin e inputeve (VRT)
- Asnjëra

20. A zotëroni/aplikoni ndonjërën nga teknologjitë bujqësore precize të lartpërmendura?

- Po
- Jo

21. Nese po, trego cilën prej tyre e aplikoni në fermën e juaj?

____

22. Cili nga faktorët e mëposhtëm mendoni se ndikon në përdorimin e teknologjive bujqësore precize? (Përgjigje të shumta janë të mundshme)

- Çmimi
- Njohuri/aftësi për përdorimin e këtyre pajisjeve teknologjike në bujqësi
- Madhësia e fermës
- Mosha
- Niveli i edukimit
- Gatishmëria

23. A mendoni se fermat e Kosovës kanë potencial për të adoptuar njërën nga këto teknologji?

- Po
- Jo

24.Pse?

____

25. A do të ishin këto teknologji të dobishme për bujqësinë në Kosovë?

- Po
- Jo

26. Specifiko arsyen pse?

____

27. A dëshironi të informoheni më shumë rreth këtyre teknologjive dhe të trajnoheni për përdorimin e tyre?
- o Po
- o Jo

28. A planifikoni të zotëroni një nga këto teknologji në të ardhmen e afërt?
- o Po
- o Jo

29. Cilen nga pajisjet teknologjike të bujqësisë precize do të dëshironit të zotëronit? (Përgjigje të shumta janë të mundshme)
- o Monitorimi i rendimentit dhe teknologjitë e hartës
- o Sistemi i pozicionimit satelitor (GPS)
- o Teknologjitë e sensorit në distance
- o Sistemet e Informacionit Gjeografik (GIS)
- o Teknologjitë e drejtimit të automobilave
- o Teknologjitë me normë të ndryshueshme për aplikimin e inputeve (VRT)

30. Cilat pajisje precize teknologjike bujqësore ju nevojiten më shumë? (Përgjigje të shumta janë të mundshme)
- o Monitorimi i rendimentit dhe teknologjitë e hartës
- o Sistemi i pozicionimit satelitor (GPS)
- o Teknologjitë e sensorit në distance
- o Sistemet e Informacionit Gjeografik (GIS)
- o Teknologjitë e drejtimit të automobilave
- o Teknologjitë me normë të ndryshueshme për aplikimin e inputeve (VRT)

31. A mendoni se aplikimi i këtyre teknologjive do të ketë një efekt pozitiv në fermën tuaj?
- o Po
- o Jo

32. Specifiko arysen pse?

____

33. A e konsideroni perdorimin e teknologjive bujqësore precize në të ardhmen e afërt?
- o Po
- o Jo
- o Neutral

In English:

1.Location of your farm (Region)?

- Prishtina
- Gjilan
- Ferizaj
- Mitrovica
- Peja
- Gjakova
- Prizren

2.Your gender?

- F
- M

3. Your age?

- 18-30 years old
- 30-40 years old
- over 60 years old

4. Highest level of education you have completed?

- Primary school
- Vocational high school or Gymnasium
- Faculty
- Master
- Doctorate
- Professional course
- No qualification

5. Off-farm employment status?

- Student
- Employed
- Unemployed
- Retired

6. Size of your farm?

____

7. In what year was your farm established?

- 2000-2010
- 2010-2015
- 2015-2022

8. Is the land ?

- Rented
- Owned

9. Type of farm?
- Small
- Medium
- Large

10. What is the main sector of activity on your farm? (Multiple answers are possible).
- Farming
- Viticulture
- Orchards
- Vegetable growing

11. Please specify the type of agricultural crop you cultivate on your farm?

____

12. Number of employees on your farm?

____

13. Types of machinery or technological equipment you use on your farm?

____

14. Do you have income outside the farm?
- Yes
- No

15. Do you follow new technological trends in agriculture?
- Yes
- No

16. Have you heard of precision farming before?
- Yes
- No

17. If yes, what is the source of information?
- Internet
- TV
- Radio
- Society
- Newspaper
- Fair
- Agricultural associations
- Colleagues

18. Do you know what precision farming is?

- Yes
- No

19. Which of these precision farming technologies are you familiar with or have you heard of recently? (Multiple answers are possible).

- Yield monitoring and mapping technologies
- Global Positioning System (GPS)
- Remote sensing technologies
- Geographic Information Systems (GIS)
- Automotive steering technologies
- Variable rate input application technologies (VRT)
- None

20. Do you own/apply any of the above precision farming technologies?

- Yes
- No

21. If yes, indicate which of them you apply on your farm?

____

22. Which of the following factors do you think influences the use of precision agricultural technologies? (Multiple answers are possible)

- Price
- Knowledge/skill in using these technological devices in agriculture
- Farm size
- Age
- Education level
- Readiness

23. Do you think that Kosovo farms have the potential to adopt one of these technologies?

- Yes
- No

24. Why?

____

25. Would these technologies be useful for agriculture in Kosovo?

- Yes
- No

26. Specify the reason why?

____

27. Would you like to learn more about these technologies and be trained in their use?

- Yes
- No

28. Do you plan to own one of these technologies in the near future?

○ Yes
○ No

29. Which precision farming technology devices would you like to own? (Multiple answers are possible)

○ Yield monitoring and mapping technologies
○ Global Positioning System (GPS)
○ Remote sensing technologies
○ Geographic Information Systems (GIS)
○ Automotive steering technologies
○ Variable rate input application technologies (VRT)

30. Which precision farming technology devices do you need the most? (Multiple answers possible)

○ Yield monitoring and mapping technologies
○ Global Positioning System (GPS)
○ Remote sensing technologies
○ Geographic Information Systems (GIS)
○ Automotive steering technologies
○ Variable rate application technologies (VRT)

31. Do you think that the application of these technologies will have a positive effect on your farm?

○ Yes
○ No

32. Specify the reason why?

____

33. Do you consider using precision agriculture technologies in the near future?

○ Yes
○ No
○ Neutral