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Article

Precision Agriculture Technologies for Crop and Livestock Production in the Czech Republic

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Abstract: Modern technologies are penetrating all fields of human activity, including agriculture, where they significantly affect the quantity and quality of agricultural production. Precision agriculture can be characterised as an effort to improve the results of practical farming, achieving higher profits by exploiting the existing spatial unevenness of soil properties. We aim to evaluate precision agriculture technologies' practical use in agricultural enterprises in the Czech Republic. The research was based on a questionnaire survey in which 131 farms participated. We validated the hypothesis through a Chi-squared test on the frequency of occurrence of end-use technology. The results showed that precision farming technologies are used more in crop than livestock production. In particular, 58.02% of enterprises use intelligent weather stations, 89.31% use uncrewed vehicles, and 61.83% use navigation and optimisation systems for optimising journeys. These technologies are the most used and closely related to autonomous driving and robotics in agriculture. The results indicate how willing are agricultural enterprises to adopt new technologies. For policy makers, these findings show which precision farming technologies are already implemented. This can make it easier to direct funding towards grants and projects.

Keywords: precision agriculture; Industry 4.0; technology; adoption; unmanned vehicles; smart production; drones; robots

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1. Introduction

Today's turbulent times bring new challenges for everyone every day. Society is constantly evolving, and so are the various technologies. The industrial revolution has proceeded gradually since the emergence of mechanisation. The Fourth Industrial Revolution has come sequentially, bringing radical changes across all industries. One of these industries is agriculture. Until a few decades ago, there were more workers in agriculture than in industry. From ancient ages until the early twentieth century, agriculture has always been very demanding, requiring a great deal of physical effort. Still, the profits from these tasks have not been significant. It used to take an average of two acres of cultivated land to feed one man. With the twentieth century came new industrial agriculture, and productivity rose radically [1,2].

Precision agriculture is the term used to describe the association of changes brought about by the Fourth Industrial Revolution in agriculture. Modern technologies enable the precision of work, efficiency, efficient processing of all data and other aspects that will move agriculture to a new level. Precision agriculture means accuracy and implies correctness or precision in any production [3]. The main objective of precision agriculture is to adapt operations to the actual location conditions with the principle of carrying out interventions in the right place, with the right intensity and at the right time. Precision agriculture is currently the most popular in the USA because of its rustic structure and technological maturity. India and North America have the highest [4] technical capacity to pursue an opportunity for smart agriculture. However, McBratney et al. [4] suggest that crop production has the highest potential for precision agriculture according to the spatial index (Ha of cropland per worker) in Canada, Australia, and the USA. Livestock production is highest according to the environmental index (fertiliser use: kg per ha of cropland) in Ireland, the Netherlands, and Egypt.

In the Czech Republic, the agrarian structure is favourable for precision agriculture, as it is dominated by large farms, large plots of land and a diversity of natural conditions combined with soil variability and rugged terrain [5]. These large farms in the Czech Republic combine modern technology, automation and robotisation with a small number of workers focused primarily on maximising production and sales. In contrast, small, family-run farms that focus mainly on quality, regional products, healthy food, horse breeding, or agro-tourism are also thriving. The overall level of involvement in precision agriculture is at a medium level [6]. The adoption of precision agriculture technologies is relatively high [7]. New technologies, the loss of land ownership, the concentration of land in large blocks and the reluctance of people to work seven days a week from morning to night have led to a significant polarisation. The main issues of Czech agriculture are labour shortages, the unfavourable economic situation of most enterprises, and expensive technology.

The main issues in farming communities without precision agriculture are related to uniform and homogenous land management [8]. In this case, the intensity of cultivation interventions is usually chosen based on the average value of the smallest unit area. The most significant advantage of precision agriculture is the ability to identify and determine variability. The primary input information is passed on from generation to generation as the primary know-how. However, agricultural sustainability depends primarily on progress in the efficient use of nitrogen [9] and other agrochemicals. Data from water, nitrogen and pesticide application during the growing season need to be recorded immediately after sensing. It creates significant advantages over traditional farming along with a reduction in human labour and resource efficiency, as outlined in the results of this paper. Thus, the conventional approach is associated with increased costs, production's economic intensity and environmental pollution risk [10]. The main ecological problem is the excessive application of agrochemicals and poorer traceability of records of soil operations. The economic impacts are mainly in the increased cost of material inputs (fertilisers, pesticides and fuel). It is impossible to achieve lower fuel consumption without navigation and satellite technology due to unfamiliarity with the terrain and the use of the optimal route. Another significant problem with these systems is the more challenging identification of harmful organisms due to incorrect demarcation of application zones. Current problems in agriculture are climate change, soil degradation, food unsafety and diversity loss [11].

For the problems mentioned above in farming communities, precision agriculture technologies may be just the solution to enable targeted local interventions. Our research focused on agricultural enterprises to capture the current trends in Czech agriculture. Previous studies of precision agriculture in the Czech Republic are limited to their narrow focus on specific technologies and timeliness. The most recent comprehensive studies date from about five years ago [12,13]. This research gap needed to be filled with current research into determining what technologies are currently the most used in agriculture. Moreover, it would fortify the perspective of enterprises. The article aims to evaluate the practical use of precision agriculture technologies in agricultural enterprises in the Czech Republic. However, there could be differences between crop and livestock production. Thus, we investigated both of these farming areas and compared the results. We stated some recommendations for policymakers and users of precision agriculture technologies.

We divided the article into the following structure: 1. Introduction with basic information on the topic; 2. Theoretical background focused on precision agriculture and technologies; 3. Materials and methods with the definition of research aim and methods; 4. Results including technologies in crop and livestock production; 5. Discussion of main findings; and 6. Conclusion.

2. Theoretical Background

The theoretical background briefly describes the current state of the research field with the definition of precision agriculture and mainly used technologies.

2.1. Definition of Precision Agriculture

Many authors [14–17] speak of revolutions in the era of industrial agriculture. The introduction of tractors brought about the first revolution, combining harvesters and mechanisation. The second revolution was triggered by the development of biotechnology, including the much-discussed genetic manipulation. Later, computer technology began to be used in agriculture to optimise and introduce new production methods.

In recent years, the term Agriculture 4.0 or Precision Agriculture has emerged. The term Industry 4.0 is derived from Agriculture 4.0 or Precision Agriculture. It refers to modern techniques and technology in agriculture to increase the precision of work, reduce costs, increase efficiency, intelligent processing, data evaluation and other aspects leading to the modernisation of agriculture. Precision agriculture is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production to improve crop performance and environmental quality [3]. Precision agriculture is already available to all farms using automatic machine control, operating a large tracked tractor or a compact tractor with a small centrifugal spreader. Furthermore, thanks to Agriculture 4.0, it is possible to save a large amount of natural and monetary resources due to the introduction of automatic section control systems and the use of locally variable nutrient applications [18].

With the global increase in land area and the size of farms, this knowledge could not be efficiently obtained. A location was treated more like a homogeneous area whose potential was not fully exploited. This situation has only been changed by the availability of technology and the necessary technical equipment. It provides the spectrum of data needed from many sources and their comprehensive analysis. The outputs help in decision-making on agronomic activities, adapting variable application of fertilisers and pesticides in the right amount at the right place or predicting the condition and characteristics of the soil or crop [19–22].

Precision technologies in livestock production have also evolved quite rapidly. Precision farming in animal nutrition and breeding is referred to abroad as Precision Livestock Farming (PLF). The aim is to improve the precision of farm operations and help the farmer make decisions immediately. New directions in modern farming focus on selecting forage crop varieties, their cultivation, harvesting, nutritional value, silage or storage, while attention is paid to feeding animals and the quality of production.

2.2. Previous Studies and Research Framework

Previous studies on precision agriculture adoption were considered to determine the research framework and questionnaire survey. This short review is focused on the classification of precision agriculture technologies and a summary of commonly used technologies.

Recent results of the Precision Agriculture Dealership Survey [23] show the importance of on-farm data for hybrid/variety selection and nutrient management. Dealers highlighted several uncrewed aerial vehicles for variable pesticide applications and crop input. Virals are GPS-guided controllers on sprayers and guidance-related technologies, which continue to grow. McKinsey Company [24] summarises precision agriculture technologies and divides technologies into five groups: smart-crop monitoring, drone farming, smart-livestock monitoring, autonomous-farming machinery, smart-building, and equipment management.

Several authors have addressed the issue of the adoption of precision agriculture technologies in the Czech Republic. Research in the Czech Republic focuses on mapping soil and crop variability, creating application maps for crop fertilisation, and determining and optimising differentiated doses of fertilisers and herbicides. Stočes et al. [25] developed the User-Technological Index of Precision Agriculture (UTIPA), which is calculated for each technology from obtained relevant data. It is an exciting application result that could help to compare familiarity or usage of the particular technology. Kasparov [26] studied the links between the nature of agricultural subjects on the perception of the attributes of precision agriculture with its adoption. In this research, respondents were asked about the technologies they use. According to application maps, the most widely used technologies were automatic section control, assisted machine travel control, correction signal payment, and variable rate applications. Farmers may not consider the prospects of this area and therefore prefer to invest less in new technologies. The Czech government has supported the adoption of precision technologies through financial incentives for new machines [27]. Research [12] confirmed that investment in agricultural robots is only around 26%.

In the USA, at the University of Nebraska-Lincoln, a study on precision agriculture technology adoption and opinions was conducted [28]. The main results show that agricultural enterprises mostly adopted technology for soil sampling, computer access to high-speed internet, yield maps, yield monitor and GPS guidance systems. According to the Agricultural Resource Management Survey (ARMS), 72% of cornfields and 70% of wheat fields used precision agriculture technologies [29]. Schimmelpfennig [30] found that large corn farms mostly adopted mapping and guidance systems. According to Maloku, adoption of precision agriculture technologies in the USA varied from one state to another. For example, Alabama and Florida predominantly adopted Lightbar Guidance, variable rate technologies, and GIS mapping software [31]. In Kansas, it was lightbar guidance, section control and variable rate fertility [32]. Scientists in Latin America and the Caribbean focused on recent trends in agriculture, new technologies and their applications [33]. Precision agriculture technologies were classified into: soil analysis and environmental assessment, drones and satellite images, remote sensors and georeferenced monitoring, mobile technology, internet of things, big data, artificial intelligence, blockchain, and robots.

The adoption of precision farming in Germany was part of the project related to personal interviews of farmers. Results show that GPS-based soil sampling, yield mapping, area measurement, auto-tracking, and site-specific basic fertilizing were the most adopted technologies [34]. In another study in Germany and Poland, essential technologies were evaluated to determine how and when they could be used for sustainable agriculture [35]. This research divides technology by type of prevailing production. The first group consists of crop production technologies such as nanotechnology, yield management, soil mapping, drones, sensors, and autonomous vehicles. The second group includes technologies for livestock production such as smart devices (position and health sensors), data and on-time software, nanotechnology, and sensors. The highest ratings were considered for collecting (sensors and drones) technologies or using (soil and yield management) data.

Precision agriculture was, according to [36], used in Denmark and the United Kingdom for about 90% of wheat, barley, oilseed rape, grass seed and peas. The most used technologies in Denmark were GPS yield mapping and grid soil sampling. In addition to these technologies, variable rate fertilisation was used extensively in the United Kingdom. In France and Sweden, yield monitors were widely used [37]. According to Cavallo [38], guidance machinery was used to a large extent in Italy. The dependence of adopting precision farming technology on economic and personal factors was studied in Hungary. According to the rankings, precision fertilisation and precision plant protection were precision farming technology's most commonly used elements. An interesting finding was that tractor guidance was a widely used element, but it was not considered a precision farming technology among farmers [16]. Trends in adopting precision farming technologies in Switzerland show that technologies with driver assistance systems are more frequently used in practice. In particular, these technologies reduce the physical labor involved in working [39].

Our research framework determines the most used precision agriculture technologies in the Czech Republic. Based on the studied literature [24], we divided the technologies according to the primary type of agricultural production. The two groups consist of technologies for crop and livestock production. These groups were further subdivided according to the kind of technology. The first group consisted of technologies focused on sensing and data acquisition (primarily sensors). The second group consisted of modern machines or robots. The research does not include some progressive technologies that fall outside both groups (e.g., genetic modification). In particular, we selected technologies for the research that were investigated in a related study. These technologies are the most cited by authors, experts and researchers. The focus on agriculture and the situation in the Czech Republic also influenced the selection of the Appendix A.

2.3. Precision Agriculture Technologies

Computers, sensors and computing technologies were developed in the 1980s, as well as improved vehicle systems (ultrasonic, optical, mechanical etc.). After the 1990s, GPS systems were viral and were used in agricultural applications. Then in quite a short time, these technologies were prohibited in agriculture due to their cost. Due to that, an alternative of machine vision technologies were used. These technologies were used to analyse which crop row structures could be observed efficiently. In 1987 a dynamic thresholding technique helped to extract information from field images. After a short time, a vision guidance system to steer a tractor relative to crop rows was used so that the tractor could automatically acquire its track in the next row [40]. The leading technologies used in precision agriculture are described below.

Precision agriculture uses the new technologies of the digital age to make farming as efficient as possible on the basis of data collection. Drones, satellite images or sensors placed on farm machinery or animal bodies constantly monitor fields, orchards, greenhouses and livestock. This technology saves fertiliser and costs, and higher yields are achieved with its application. It also prevents the overuse of fertilisers and leads to a more environmentally friendly land use [41–43]. Sensor data is processed using information and communication technologies, improving herd management strategies and the farm's economic, social and environmental performance [44–46].

The sensors are mainly included in satellites, ground-based platforms, etc. Ground-based platforms can be divided into three categories: handheld, free-standing in the field, and mounted on tractors or farm machinery. The sensors are used for spatial, spectral, radiometric applications, etc. [47,48]. Remote sensing is used for yield projection, land use classification, biomass estimation, pH measurements, etc. It can be used as a tool for making decisions (e.g., subplot scale). The level of digital agriculture is rapidly growing, and supra-national monitoring is performed using on-farm management tools [49–51].

Sensor data is processed using information and communication technologies, resulting in improved herd management strategies and economic, social and environmental performance of farms. Due to improving technologies, larger volumes of data need to be processed, analysed, and stored. Big Data are also described as data volumes, which are very difficult to process and manage using analytical tools. Databases and storage systems have been created to save the data in real-time and use them for further analyses. These storages are also very helpful for utilising Big Data for agricultural decision support tools. A PDI system is used to process Big Data and helps to innovate, standardise, automate and integrate the data [28,52–55].

Precision farming has become connected to service-oriented architecture services, which help process raw data and extract useful information. New disciplines such as IoT-based companies, automated industries or businesses have been used. Ontology is applied to make the extraction of valuable data easier. Ontology uses many supporting systems, domains, and knowledge. Other authors have developed support systems such as Plants ontology, SAAONT, AgriOnt, etc. [14].

Augmented reality (AR) is a unique application that provides its users with a direct or indirect view of a natural environment (the real world), parts of which are supplemented—augmented or enriched—with additional digital visual elements. AR has many benefits in agriculture because it is possible to create a relationship with other smart city-based technologies (GPS integration etc.) It is possible to couple AR with IoT data, which is one of the benefits of AR [46]. Especially CCD cameras are beneficial in precision agriculture because they capture two-dimensional colour images from which animal information is captured. All of these images can be used for further analysis. One of the ways to use the images captured by CCD cameras is a specification of pig parameters (weight, circumference, height and other body information). Pig identification could be as follows [40,56,57]: facial recognition, live weight detection, growth patterns and mass calculation, and individual pig identification and tracking.

Robotic systems can be involved based on the used applications. Uncrewed Ground Vehicles (UGV) and Unmanned Aerial Vehicles (UAVs) are used in precision agriculture [58]. The biggest challenges in the case of UAVs are costs. Sensors, flight duration, data analytics or requirements are the most significant part of the paid costs for UAVs. Another challenge is data analytics, which needs to be done periodically. The vast data storage of numerous terabytes must be available to store all the data that needs to be analysed. Weather is also a challenge that makes the results of UAV analysis worse due to weather conditions (rain, snowfall, clouds, etc.) [59].

The technology for monitoring crops and soil from the air uses an uncrewed aerial vehicle—a drone. This device can provide the user with multispectral images of soil blocks and can cover up to hundreds of hectares in one flight. The advantage of these devices is that the resolution of the images is higher than that offered by satellite imagery. The photos are then processed using software installed on the user's computer or in a cloud environment [59–61]. Drone outputs are crucial to increasing revenue, reducing costs, and improving business efficiency. The map can also inform which areas need more detailed scouting for effective planning—meaning less time spent examining soil blocks and more time tending the crops that need it.

Another essential step towards more efficient farming is satellite-guided tractor technology. Autonomous steering and turning or control via a touch panel linked to a central system that controls everything and obtains real-time harvest and position data is also standard in the domestic market. The system also allows variable dosing of fertilisers and products. Yields can also be charted thanks to the information recorded by the machine. The system provides information on area threshed, fuel consumption, or working hours. Entrepreneurs can then use this to analyse the profitability of the land. The data obtained can also be easily used for administration and subsidy applications. International satellite navigation systems are used in precision agriculture and conventional farming, and is helpful especially during lower visibility or in case of fatigue in workers [62].

Self-driving tractors have been around for some time and operate on autopilot. The tractor does most of the work, and the farmer only steps in when needed. The technology works with the help of GPS, and the machine spreads fertiliser or ploughs. There is also a device that works on the principle of solar power and can identify the weeds it kills with a dose of herbicide or lasers. Apps available for smartphones can also be used for precision farming. By configuring a precision farming system integrated into a smartphone, it is possible to monitor all the necessary data via the mobile phone. The applications are easily portable, affordable, and have high computing power [63,64].

Another vital area is crops' highly regulated genetic modification (GM) (soybeans, cotton, canola, etc.). Now there is genome editing (GE), which avoids potential risks to human health. These risks are avoided in the GM crops with their productivity, environmental tolerance, and pest resistance. GM crops are currently superseded by GE. In the case of GM crops, by inserting or removing one of the genes or part, the organism changes its specific traits. The development of GM crops is very regulated, and it also needs licenses and approved isolation procedures for field trials. Due to that, the GE techniques (NGTS/OGTR) are well used primarily in Australia to increase the production and tolerance of abiotic and biotic stresses. These techniques rapidly increase costs and exclude GM/GE research and development by small research organisations [65]. One of the introductory chapters of Precision Agriculture is hydroponic farms, which take the form of now commonly available home-grown boxes where seeds are planted; a mobile app runs a program for different types of plants to help oversee successful growth. Hydroponic farms can take the form and size of shipping containers that offer a harvest equivalent to the production of a two-acre farm.

3. Materials and Methods

Industry 4.0 and new technology are primarily applied in the automotive and manufacturing industries, and has a lot of potential in agriculture. The article's main aim is to evaluate the practical use of precision agriculture technologies in agricultural enterprises in the Czech Republic. We wanted to determine whether particular technologies are used more or less frequently in enterprises.

3.1. Data Sample and Research Design

Our research included a questionnaire survey. We created a questionnaire using an online web platform and then sent it to enterprises' email addresses via a web link. The respondents were managers of enterprises involved in crop and livestock production. In some cases, mixed enterprises used both types of production. Data were collected from January to March 2022. The questionnaire was sent to approximately 1500 enterprises, and the total number of responses received was 131, corresponding to a return rate of roughly 8.7% [6]. According to [66], about 89,320 subjects with recognised activities operate in the agriculture, forestry and fishing industry in the Czech Republic. The sample size margin of error at a 95% confidence level was about 8.56%.

We surveyed the size of enterprises by the number of employees. The most significant percentage (49.62%) is small businesses employing 11–50 employees. Next, 28.24% of medium-sized enterprises operating with 51–250 employees were represented in the sample. A total of 21.37% of the enterprises fell into the group of micro-enterprises and employed no more than ten people. Only one enterprise (0.76%) employed more than 250 employees. By legal form of business, they include limited liability enterprises (32.06%), joint-stock enterprises (30.53%), cooperatives (24.43%), self-employed farmers (7.63%), and finally, independent entrepreneurs (4.58%). Finally, we surveyed the predominant type of production, where 25.19% of enterprises are primarily focused on crop production, 6.87% on livestock production and 67.94% on both types of production.

The survey questions concern information obtained through the literature or publicly available studies. The questionnaire consisted of four areas according to the technologies: sensors in crop production, machines in crop production, sensors and IoT devices in livestock production, robots and mobile technology in livestock production. The questions dealt with individual technologies. Respondents were asked about the frequency of occurrence of end-use technology.

3.2. Research Methods and Hypotheses

The results of the technology-related questions were statistically evaluated. We used the Chi-squared test to prove the agreement of frequency distributions for quantitative attributes of each technology. It assesses the difference between the observed frequencies (f_o) and the relative expected frequencies (f_e) that fit the predicted probability distribution. We chose for the theoretically expected frequencies an equal distribution of "yes" and "no" responses (i.e., a probability ratio $p = 0.5$). It decides whether the difference between the empirical and theoretical frequencies is random and comes from a normal population distribution. We formulated a working hypothesis as follows:

H_1: Precision Agriculture technology is used by more than half of the enterprises.

We used a statistical test to check whether the probability p of technology frequency was equal to (H_0: $p = 0.5$; when observed frequencies f_o are similar to expected frequencies f_e) or higher than 0.5 (H_A: $p > 0.5$; when observed frequencies f_o are higher than anticipated frequencies f_e). We tested the hypothesis separately for each technology listed in the questionnaire.

We evaluated the hypothesis via *p*-values for a one-sided statistical test. If the null hypothesis H_0 could be rejected at the 0.05 significance level, the observed relative frequencies differed from the theoretical ones. It implies that the technology was used in over half of the observed enterprises. The test statistic follows the Chi-square distribution, designated by χ^2 [67,68]:

$$\chi^2 = \sum \left[\frac{(f_o - f_e)^2}{f_e} \right] \quad (1)$$

with $k - 1$ degree of freedom, where:

k is the number of categories.

f_o is and observed frequency in a particular variety.

f_e is an expected frequency in a specific variety.

4. Results

This section outlines the study's results divided into four parts: sensors and machines in crop production, and sensors and robots in livestock production.

4.1. Sensors in Crop Production

The use of sensors is the first step toward precision agriculture. We examined the reasons for the application of sensors and types of sensors. The questionnaire survey results are summarised in Figure 1. A total of 58.02% of enterprises reported that the sensors detect weather conditions and have a weather station function. This function is essential in determining the local weather forecast for a specific location. It provides farmers with information on rainfall, wind speed, wind direction, humidity and temperature and atmospheric pressure. A complete overview of the conditions in the field from the nearest weather station is available. Equally important was the use of sensors for plant protection and nutrition in 53.44%, which leads to the application of substances in only the necessary places. Modern sensors may have built-in rules and algorithms that create dynamic prediction capabilities for the degree of disease risk. It is followed by the option of using sensors for machine positioning, which covered 50.38%. The fundamental advantage of field automation is the stable position and precise dimensions of each cultivated area, which facilitates the basic orientation of the machines. In addition, the direct visibility of the sky also allows satellite navigation to detect and control the position of automated devices. The less frequent option was the sensor function detecting the immediate technical condition. A total of 40.46% of respondents selected this answer. Farmers do not address monitoring machinery's technical situation. Thus, the use of machinery for agricultural work may be still associated with a higher risk of necessary repairs and maintenance. Sensors are used the least to detect crop anomalies, in 21.37%. The main idea is to apply spray only when unavoidable and choose the right time and product.

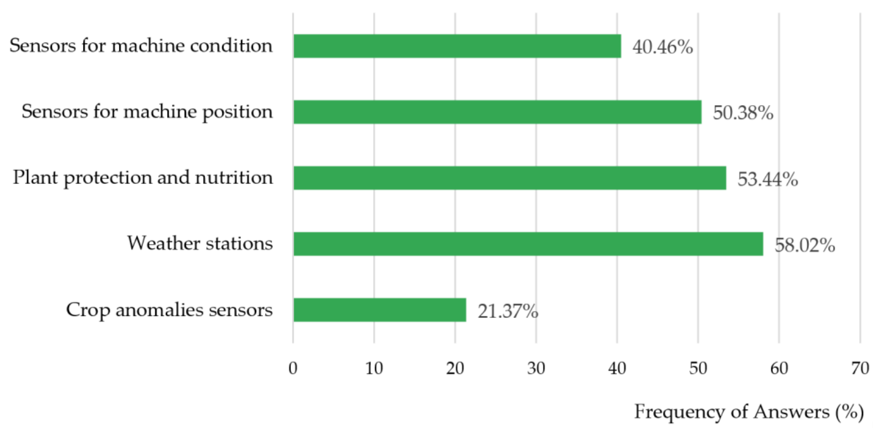

Figure 1. Use of sensors in crop production.

We performed a statistical evaluation of the responses to the survey questions related to sensors in crop production using the Chi-square test. Through working hypothesis H_1, we tried to show statistically significant differences from the mean (see Table 1).

Table 1. Results of statistic evaluation for sensors in crop production.

Technology	χ^2	*p*-Value (H_1)
Machine condition sensors	4.7710	0.9856
Machine position sensors	0.0076	0.4652
Plant protection and nutrition	0.6183	0.2159
Smart weather stations	3.3664	0.0333 *
Crop anomalies sensors	42.9389	1.0000

* the statistically significant differences at the significance level of 5% are marked.

We can prove working hypothesis H_1 that more than half of the enterprises use precision farming technology only for weather stations (p-value = 0.0333). It means that the use of this technology is really above average among enterprises. Modern sensors bring new functionalities to mobile applications. Agronomists no longer have to walk miles around the farm every day, checking the current status of the field or stored crop. Sensors provide accurate, updated data online, so they can work much more efficiently and only go where they need to at the time.

4.2. Machines in Crop Production

Drones and self-driving machines are the essential technological contributions of precision agriculture. It can be seen in Figure 2 that 89.31% of enterprises use uncrewed vehicles such as tractors and working machines in crop production. Automatic steering systems are offered by tractor manufacturers already fully integrated into the machine and built-in during its manufacture. The system's control is integrated into the tractor's control terminal. The driver simply enters the machine parameters, records the first pass on the plot, and the autopilot then controls the machine without driver intervention. The human driver only controls the speed of travel and the work of the attachment and monitors obstacles but does not intervene in the steering. The less-used technology of drones for detecting the immediate state of the soil or directly for planting seeds is used by 33.59% of enterprises. Precise mapping of agricultural land would be very time-consuming and technically challenging if it were not for aerial vehicles equipped with specialised sensing technology. Images taken from the air are evaluated and processed into application maps and orthophotos quickly, precisely and efficiently. They can be used to dose fertilisers and sprays accurately, thus exploiting the field's full potential. Instead of uniform tillage, they allow monitoring of soil conditions and dividing areas into several zones that can be approached differently. This technology is probably yet to achieve a "boom" in usage. Drones and drones are not yet used to any significant extent. In both cases, the navigation systems and optimisation software of journeys is a suitable complement to these machines, especially for tractors. This option was indicated by 61.83% of enterprises.

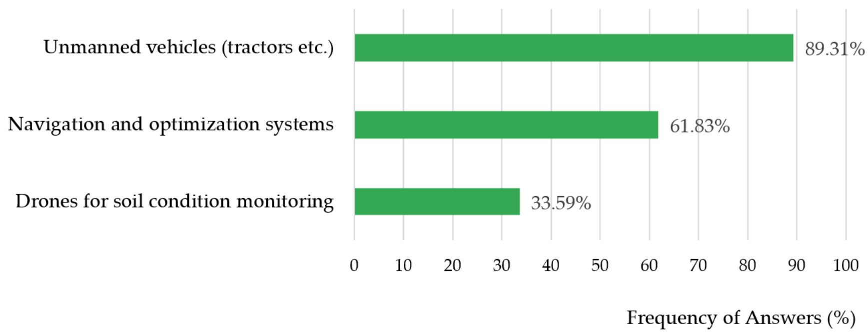

Figure 2. Use of machines in crop production.

The results of the evaluation of working hypothesis H_1 for Machines in Crop production using the Chi-square test are presented in Table 2.

Table 2. The result of statistic evaluation for machines in crop production.

Technology	χ^2	***p*-Value (H_1)**
Unmanned vehicles	80.9847	<0.0001 *
Navigation and optimisation systems	7.3359	0.0034 *
Drones for soil condition	14.1145	0.9999

* The statistically significant differences at the significance level of 5% are marked.

We succeed in proving the working hypothesis H_1 that more than half of the enterprises use precision farming technologies for uncrewed vehicles and tractors (p-value < 0.0001) and navigation and optimisation systems for journeys (p-value = 0.0034). According to the above-average results, self-driving tractors and machines can be considered the main benefit of precision agriculture. The self-driving tractor is most often equipped with GPS and terrain mapping technology, thus achieving better efficiency and lower labour costs when cultivating the field. Equally important is route optimisation software, which allows the planning of fieldwork.

4.3. Sensors and IoT Devices in Livestock Production

The next part was dedicated to finding the purpose of using sensors and IoT in livestock production. Smart collars are typical IoT devices using various sensors and performing multiple functions. Figure 3 shows the reasons for using sensors in livestock production. According to the answers, these are most often used as intelligent collars for animals, whose function is to control movement. This answer was selected by 46.56% of enterprises. These smart collars protect grazing animals from theft and help farmers find them quickly if they accidentally escape from the pasture. The second most frequently identified answer is using sensors applied to smart collars with information about animal health. A sensor on the collar senses some of the animal’s vital signs. If the animal starts behaving abnormally and the data from the collar deviates from average, it usually means that some health complications are coming. Thanks to the monitoring system, the farmer can react ahead of time and treat the animal earlier or administer vitamins before the disease fully erupts. In this case, 42.75% of enterprises selected this option, followed by intelligent collars with sensors controlling animal nutrition, 2.06%. This technology can help estimate the live weight or health status of animals. The feeding curve can then be modelled accordingly, thus avoiding overfeeding or deterioration of animal health. The last was the possibility of using sensors that can handle the microclimate in the stables in 32.06% of enterprises. Farmers have a system installed in the barn to control the barn microclimate and help maintain it at the necessary values. Sensors check the temperature and humidity of the air or the content of certain gases and adjust the covering of the side walls, the opening of vents, and the running of fans or showers to cool the animals as needed. However, nowadays, it is more typical to use classical recommendations or best practices to create optimal conditions for livestock.

Furthermore, we evaluated working hypotheses H_1 for sensors and IoT devices in livestock production. The results of the Chi-square tests are summarised in Table 3.

We cannot prove hypothesis H_1 that more than half of the enterprises use precision farming technologies for one of the sensors and IoT devices in livestock production. Intelligent collars and microclimate sensors are not yet widely used, and the occurrence of smart collars for health and nutrition monitoring is less frequent in enterprises.

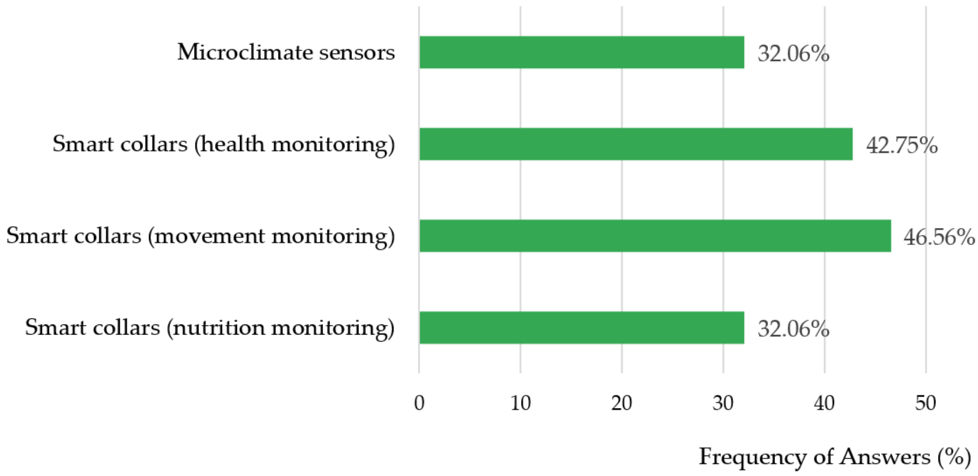

Figure 3. Use of sensors and IoT devices in livestock production.

Table 3. The results of statistical evaluation for sensors and IoT in livestock production.

Technology	χ^2	p-Value (H_1)
Microclimate sensors	16.8626	1.0000
Smart collars (health monitoring)	2.7557	0.9516
Smart collars (movement monitoring)	0.6183	0.7842
Smart collars (nutrition monitoring)	16.8626	1.0000

The statistically significant differences at the significance level of 5% are marked.

4.4. Robots in Livestock Production

The last part is devoted to finding the use of robots in agriculture enterprises. In the future, the automation and robotisation of agriculture are considered one of the most dynamic developments, not only in processing crops, which is already quite common today but also in the cultivation of the fields themselves. Indeed, an “army” of new, more accurate and robust monitoring sensors are set to come into play in a major way, which, in conjunction with more powerful control units, will enable existing types of agricultural machinery to be controlled automatically or semi-automatically. About 19.85% of livestock farmers use robots to feed their animals, and 12.98% of enterprises use milking robots in their business. The animals have freedom of movement, and no one chases them to milk. When they need to be milked, they walk to the robot. When they need to be fed, they walk to the gutter, and when they need to rest, they lie down. These results show that robot technology is not yet widespread in agriculture. The use of robots is, therefore, still very much in the future (see Figure 4).

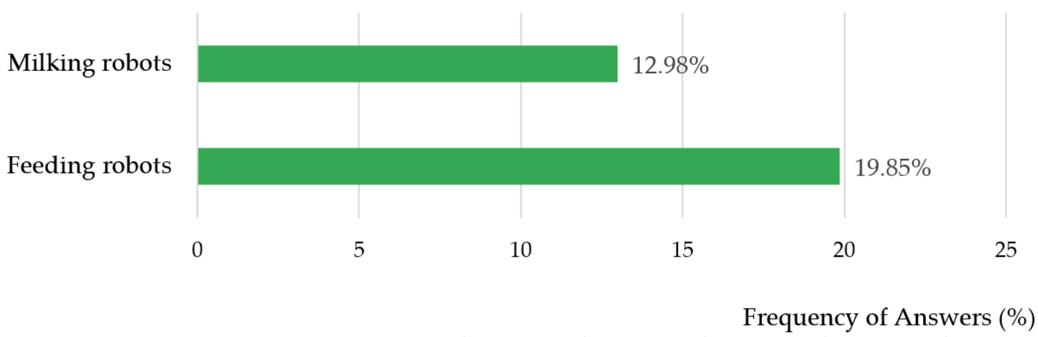

Figure 4. Use of Robots in Livestock Production.

In Table 4, we present the results of the evaluation of working hypothesis H_1 for using robots in livestock production.

Table 4. The results of statistical evaluation for robots in livestock production.

Technology	χ^2	p-Value (H_1)
Milking robots	71.8244	1.0000
Feeding robots	47.6412	1.0000

The statistically significant differences at the significance level of 5% are marked.

In the statistical evaluation of hypothesis H_1, we could not confirm that more than half of the enterprises use the technology of precision agriculture robots in livestock production. The deployment of robots in agriculture is not yet at a high level. The results showed shallow usage values for both milking robots and feeding robots. It means that enterprises still do not favour the advantages of automatic processes.

5. Discussion

This section discusses the results from the perspective of previous studies and the working hypotheses. Future research directions and limitations of our study are highlighted.

5.1. Technology of Precision Agriculture

Furthermore, we focus on technology used by enterprises. Discussion is divided into two parts according to technology usage by enterprises.

5.1.1. The Most Used Technology

First, we focus on technologies more widely used by enterprises. In our case, this confirms working hypothesis H_1, where we hypothesised that more than half of the enterprises would use precision agriculture technology. Our research showed that precision agriculture technologies are predominantly used in crop production. After all, most definitions of the term [3] refer to activities and operations on cultivated land. Moreover, the results showed that most farms do not use sensors, IoT devices and robots. Thus, working hypothesis H_1 was confirmed only for some of the technologies used in crop production. The most widely used precision agriculture technologies are intelligent weather stations, uncrewed vehicles, and navigation and optimisation systems for journeys. Similarly, according to technology expert evaluations [18], the most promising precision agriculture technologies are robots, autonomous machines, sensors, and global navigation satellite systems.

In our research, 89.31% of enterprises used driverless vehicles, such as tractors and machines. These vehicles not only move on the ground but also receive weather data via an internet connection and can also make decisions based on it. According to Kasparov [26], the most widely used technologies in agriculture are those that facilitate machine control and navigation, i.e., automatic section control by 30% of enterprises, and assisted machine travel control by 21% of enterprises. We can conclude that companies have learned to work with these technologies, and the share is gradually increasing. In 2015, USA auto-steer technology was used in about 70% of farms [28] to improve operator performance and reduce excess input usage.

GPS navigation and mapping are the technologies that farmers usually start with and are the most widely used [34]. Our research found that 61.83% of enterprises use navigation systems. Similar results were reported in research [12], where the investment of agricultural enterprises in the Czech Republic in navigation systems is about 70%. In Hungary, 12% of farmers used GPS only for field navigation, not site-specific measures [16]. In Latin America and the Caribbean, sensors for geolocation are used by 36% of farmers [33]. The use of navigation is related to optimising the route and land travel. It is done by special software that records the boundaries of the plot and then can optimise routes for the farmer according to the shape of the property to minimise the number of journeys. Other research that reports on navigation systems use is the Precision Agriculture Dealership Survey [23]. These results show that GPS guidance systems with automatic control are utilised for fertiliser/chemical application in 81%, satellite/aerial imagery in 67%, and GPS to manage vehicle logistics and track locations of vehicles and guide them in 47%. It is becoming apparent from the results of these studies that navigation systems are the most widely used precision agriculture technology overall.

We found that 58.02% of enterprises used weather stations for monitoring and detecting weather conditions. We do not have a direct comparison in this area. However, for example, in Latin America and the Caribbean, 41% mainly used remote sensors [33]. The advantage of these sensors is access to up-to-date data on weather and conditions without the need to walk around the plot and record readings manually. These technologies are prevalent and have utility in precision irrigation, field monitoring and spraying [69].

5.1.2. The Less Used Technologies

Finally, we investigated which precision agriculture technologies are less used by enterprises. We divided the results into two parts: crop production and livestock production.

We found that crop production has an intermediate usage of machine position sensors with 50.38% and plant protection and nutrition sensors with 53.44%. The least used technologies in crop production are machine condition sensors, crop anomaly sensors, and drones. However, some research shows that these technologies could have higher potential. For example, Germany and Poland's highest readiness levels include technology drones, sensors, and soil management systems [35]. Smart-crop monitoring included corresponding sensor data and imagery analysis to optimise resource usage based on location. McKinsey Company estimated the highest range of new global GDP value potential in smart-crop monitoring [24].

In livestock production, 46.56% of enterprises indicated intermediate level usage of smart collars for animal movement monitoring. For livestock production, the least used technologies are microclimate sensors, smart collars for health and nutrition monitoring, and milking and feeding robots. Similarly, research [12] showed that 52% of sensors are used in livestock production to detect newborn calves, peak estrus, health problems, etc. The intelligent tracking collar uses mostly modern GPS technology through which the farmer receives accurate information about the current location of the animals. Monitoring is done through communication between the tracking collar worn by the animal and the base station. Some more sophisticated models communicate with a mobile phone.

It was evident that fewer farmers used leading technologies in livestock production. We, therefore, tried to find an explanation for this situation. One of the reasons why the area of livestock production is not very well developed is that animal breeding in the Czech Republic has been declining recently [70]. Farmers may not consider the prospects of this area and therefore prefer to invest less in new technologies. Research [12] confirmed that investment in robots is only around 26%. Market conditions are conducive to this, and it is questionable whether the current situation is sustainable. Unlike crop production, livestock production is year-round. It, therefore, requires deploying technological and human resources throughout the year, which is a disadvantage for personnel requirements. Livestock production takes place in less variable environmental conditions, unlike crop production. It means that there is higher variability in crop production. Therefore, there is a greater need for modern technologies to cope with this variability. In livestock production, animal nutrition is easily adjustable. Feeding and aftercare needs can be easily predicted. For example, controlled and automated feeding for cows is necessary for above 8000 litres of milk production. For plants, it is more complicated, as nutrient levels depend on soil conditions and fertiliser. In addition, some fertilisers (nitrogen) are easily leachable, affecting fertilisation's overall efficiency. In crop production, the progress and development of plant growth take place in a short time compared to livestock production.

5.2. Future Research

We have identified research gaps that could be further developed from the results of our research and that of other authors. The first challenge is to compare the precision industry's overall level in each country. From the available sources, it has become apparent that this assessment has been done to a limited extent. It is unsuitable for comparison due to differing methodologies across countries. The second challenge is identifying factors that help or hinder the adoption of precision agriculture. Various analyses have already been undertaken in this area, mainly concerning agricultural policy and subsidies. A third research area could be the development of specific case studies of technologies and their use in agriculture. These case studies highlight the advantages of this approach for farmers who have not yet decided to deploy new technologies. Some other streams of research include, for example, a study by McBratney et al. [4] focusing on employers training to acquire knowledge about new technologies, environmental damage costs or economic assessment of precision agriculture.

5.3. Limitations

The limitation of this research may be the sample composition and size, created based on a non-probability sampling method. We used purposive sampling based on our knowledge about the population and the study research aims. Another problem could be the relatively high sample size margin of error of 8.56%. It indicated less likelihood of relying on the results of a survey. Therefore, the confidence in the results will be lower to represent a population. However, the results of other studies show that usage of technologies is very similar to their effects. Therefore, we believe that the results are consistent with the conclusions of the other authors.

Some technologies were not part of the research, such as nanotechnology in livestock production [71], genetic modification [72], automatic planting of seeds in the field, mapping technologies, camera-based imaging, data analysis, and evaluation technologies [73]. The questionnaire was based on what was generally known about agriculture in the Czech Republic. For the selected technologies, we confirmed their use on farms. However, some technologies have been applied in practice only marginally. An overview and description of other precision agriculture technologies include a Smart Farming Platform database (smart-akis.com, accessed on 5 April 2022).

6. Conclusions

Precision agriculture, supported by modern technology, is looking for ways to optimise management. Farmers can better determine what is efficient, cost-effective and time-saving from the knowledge gained. New technology and modern machinery should therefore be thoroughly fostered. However, emphasis should be placed on promoting farming characterised by a broader understanding of local conditions. Digital advances and their implementation are occurring in both livestock and crop production. Automation and electronic data transmission help eliminate the human factor deficit. In our article, we aimed to determine the usage of precision agriculture technologies in agricultural enterprises.

We summarised the results of the technology usage in crop production. In that case, we can conclude that the most used technologies are intelligent weather stations, unnamed vehicles, and navigation and optimisation systems for optimising journeys. We showed that more than half of the enterprises surveyed use these technologies. These technologies can be introduced gradually and create synergies. Thus, we can say that they are more widespread, and the enterprises are solving their daily issues with them. The advantage of autonomous machines in agriculture is to increase productivity and quality and reduce land management costs. Their application is therefore justified for farmers and is already changing the face of agriculture today. Agriculture can consequently be very promising using the latest technological solutions.

Summarising the results of the use of technology in livestock production, we can conclude that precision agriculture principles are not yet widespread in livestock production. Instead, existing animal management practices are used, and only a small number of farms are trying to introduce new technologies. Of these, smart collars for movement are currently the most widely used, often to protect animals from theft, loss or straying. Gradually, with the development of 5G networks and the use of robotics in manufacturing, this situation will change in the future.

Given the anticipated focus of European Union agricultural policy on reducing environmental impact, we consider the use of modern information technology inevitable. Knowing which technologies make sense to support and have future applicability is essential. On the other hand, it is clear that in livestock production, the benefits of technologies still need to be further monitored and communicated to potential farmers. Modern technology should be available to large businesses and small entrepreneurs. Farmers want subsidies and less bureaucracy. Technology can help and benefit everyone. For this reason, it is necessary to educate about information technology so that even older farmers can start to use the new systems.

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Appendix A

The questionnaire survey is listed below:
The name of the company (optional):
The legal form of business (select one option)

- Limited liability enterprise
- Joint-stock enterprise
- Cooperatives
- Self-employed farmer
- Independent entrepreneur
- Other

Number of employees (select one option)

- Less than ten employees
- 11–50 employees
- 51–250 employees
- More than 250 employees

The predominant type of production (select one option)

- Crop production
- Livestock production
- Both types (mixed) production

Do you use sensors in crop production? (select one or more options)

- For detecting the instantaneous technical condition of machinery.
- To detect the instantaneous position of the machine.
- For plant protection and nutrition: application only at necessary points on the plot.
- For detecting weather conditions (smart weather stations).
- For the ability to detect anomalies in crops.
- Others

Do you use machines in crop production? (select one or more options)

- Unmanned vehicles in crop production (tractors, work machines)
- Navigation and optimisation systems for optimising journeys around the field
- Drones for the detection of the instantaneous state of the soil condition.
- Others

Do you use of sensors in livestock production? (select one or more options)

- Sensors to control the microclimate in the stables
- Smart collars for animals, controlling their health
- Smart collars for animals, controlling their nutrition
- Smart collars for animals, controlling their movement
- Others

Do you use robots or mobile technology in livestock production? (select one or more options)

- We use robots to feed animals
- We use robots for milking
- Others

References

1. Yang, J.; Guo, X.; Li, Y.; Marinello, F.; Ercisli, S.; Zhang, Z. A Survey of Few-Shot Learning in Smart Agriculture: Developments, Applications, and Challenges. *Plant Methods* **2022**, *18*, 28. [CrossRef] [PubMed]
2. Alkan, A.; Abdullah, U.M.; Abdullah, O.H.; Assaf, M.; Zhou, H. A Smart Agricultural Application: Automated Detection of Diseases in Vine Leaves Usinghybrid Deep Learning. *Turk. J. Agric. For.* **2021**, *45*, 717–729. [CrossRef]
3. Pierce, F.J.; Nowak, P. Aspects of Precision Agriculture. In *Advances in Agronomy*; Elsevier: Amsterdam, The Netherlands, 1999; Volume 67, pp. 1–85. ISBN 978-0-12-000767-7.
4. McBratney, A.; Whelan, B.; Ancev, T.; Bouma, J. Future Directions of Precision Agriculture. *Precis. Agric.* **2005**, *6*, 7–23. [CrossRef]
5. Lukas, V.; Neudert, L.; Křen, J. Precizní Zemědělství a Jeho Přínosy [Precision Agriculture and Its Benefits]. Available online: https://zemedelec.cz/precizni-zemedelstvi-a-jeho-prinosy/ (accessed on 1 January 2022).
6. Svepesova, I. *Průmysl 4.0 v Zemědělství [Industry 4.0 in Agriculture]*; University of South Bohemia in Ceské Budejovice, Faculty of Economics: Ceske Budejovice, Czech Republic, 2022.
7. Kušová, D.; Těšitel, J.; Boukalová, Z. Willingness to Adopt Technologies of Precision Agriculture: A Case Study of Tech Czech Republic. *WIT Trans. Ecol. Environ.* **2017**, *220*, 109–117. [CrossRef]
8. Li, Q.; Hu, G.; Jubery, T.Z.; Ganapathysubramanian, B. A Farm-Level Precision Land Management Framework Based on Integer Programming. *PLoS ONE* **2017**, *12*, e0174680. [CrossRef]
9. Späti, K.; Huber, R.; Finger, R. Benefits of Increasing Information Accuracy in Variable Rate Technologies. *Ecol. Econ.* **2021**, *185*, 107047. [CrossRef]
10. Pánková, L.; Aulová, R.; Jarolímek, J. Economic Aspects of Precision Agriculture Systems. *AOL* **2020**, *12*, 59–67. [CrossRef]
11. Zhang, Y.; Min, Q.; Li, H.; He, L.; Zhang, C.; Yang, L. A Conservation Approach of Globally Important Agricultural Heritage Systems (GIAHS): Improving Traditional Agricultural Patterns and Promoting Scale-Production. *Sustainability* **2017**, *9*, 295. [CrossRef]
12. Duspivová, K.; Nesrstová, M.; Miklová, M.; Doleželová, P. *Vliv Digitalizace a Robotizace Na Charakter Práce a Roli Sociálního Dialogu v Zemědělství [The Impact of Digitalization and Robotization on the Nature of Work and the Role of Social Dialogue in Agriculture]*; Trexima: Zlín, Czech Republic, 2018.
13. Novak, R.; Hrtusova, T. Precizní Zemědělství v Praxi [Precision Agriculture in Practice]. Available online: https://cdn0.erstegroup.com/content/dam/cz/csas/business_csas_cz/precizni-zemedelstvi/Precizni_zemedelstvi_v_praxi_2018_02.pdf (accessed on 10 February 2022).
14. Fahad, M.; Javid, T.; Beenish, H.; Siddiqui, A.A.; Ahmed, G. Extending ONTAgri with Service-Oriented Architecture towards Precision Farming Application. *Sustainability* **2021**, *13*, 9801. [CrossRef]
15. Lee, C.-L.; Strong, R.; Dooley, K.E. Analyzing Precision Agriculture Adoption across the Globe: A Systematic Review of Scholarship from 1999–2020. *Sustainability* **2021**, *13*, 10295. [CrossRef]
16. Lencsés, E.; Takács, I.; Takács-György, K. Farmers' Perception of Precision Farming Technology among Hungarian Farmers. *Sustainability* **2014**, *6*, 8452–8465. [CrossRef]
17. Mulla, D.J. Twenty Five Years of Remote Sensing in Precision Agriculture: Key Advances and Remaining Knowledge Gaps. *Biosyst. Eng.* **2013**, *114*, 358–371. [CrossRef]
18. Fuka, V. Zemědělství 4.0–Co to Vlastně Je? [Agriculture 4.0–What Is It?]. Available online: https://mechanizaceweb.cz/zemedelstvi-4-0-co-to-vlastne-je/ (accessed on 12 February 2022).

19. Balafoutis, A.T.; Evert, F.K.V.; Fountas, S. Smart Farming Technology Trends: Economic and Environmental Effects, Labor Impact, and Adoption Readiness. *Agronomy* **2020**, *10*, 743. [CrossRef]
20. Mendes, J.; Pinho, T.M.; Neves dos Santos, F.; Sousa, J.J.; Peres, E.; Boaventura-Cunha, J.; Cunha, M.; Morais, R. Smartphone Applications Targeting Precision Agriculture Practices—A Systematic Review. *Agronomy* **2020**, *10*, 855. [CrossRef]
21. Bhatnagar, V.; Poonia, R.C.; Sunda, S. State of the Art and Gap Analysis of Precision Agriculture: A Case Study of Indian Farmers. *Int. J. Agric. Environ. Inf. Syst.* **2019**, *10*, 72–92. [CrossRef]
22. Gagliardi, G.; Lupia, M.; Cario, G.; Cicchello Gaccio, F.; D'Angelo, V.; Cosma, A.I.M.; Casavola, A. An Internet of Things Solution for Smart Agriculture. *Agronomy* **2021**, *11*, 2140. [CrossRef]
23. Erickson, B.; Lowenberg-DeBoer, J. *Precision Agriculture Dealership Survey*; Purdue University: West Lafayette, Indiana, 2020; Volume 2020.
24. Goedde, L.; Ménard, A.; Revellat, J. Agriculture's Connected Future: How Technology Can Yield New Growth. Available online: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth (accessed on 9 June 2022).
25. Stočes, M.; Jarolímek, J.; Charvát, K.; Masner, J.; Pavlík, J.; Vaněk, J. *User-Technological Index of Precision Agriculture*; Precision Agriculture Association New Zealand: Hamilton, New Zealand, 2017; pp. 1–7.
26. Kasperová, M. Precizní Zemědělství v Česku: Kvantitativní Analýza Faktorů Ovlivňujících Jeho Osvojení. In *Precision Agriculture in the Czech Republic: A Quantitative Analysis of Factors Influencing Its Adoption*; Masaryk University: Brno, Czech Republic, 2018.
27. Mrnuštík Konečná, M.; Sutherland, L.-A. Digital Innovations in the Czech Republic: Developing the Inner Circle of the Triggering Change Model. *J. Agric. Educ. Ext.* **2022**, *28*, 1–24. [CrossRef]
28. Castle, M.; Lubben, D.B.; Luck, J. Precision Agriculture Usage and Big Agriculture Data. *Cornhusker Econ.* **2015**, *2015*, 1–3.
29. U.S. Department of Agriculture Tailored Reports: Precision Agriculture. Available online: https://data.ers.usda.gov/reports.aspx?ID=17883 (accessed on 15 February 2022).
30. Schimmelpfennig, D. *Farm Profts and Adoption of Precision Agriculture*; USDA Economic Research Service: Washington, DC, USA, 2016.
31. Winstead, A.T.; Norwood, S.H.; Griffin, T.W.; Runge, M.; Adrian, A.M.; Fulton, J. *Adoption and Use of Precision Agriculture Technologies by Practitioners*; The International Society of Precision Agriculture (ISPA): Monticello, IL, USA, 2010; pp. 18–21.
32. Griffin, T.W.; Yeager, E.A. How quickly do farmers adopt technology? A duration analysis. In Proceedings of the Precision agriculture '19, Montpellier, France, 8 July 2019; Wageningen Academic Publishers: Montpellier, France, 2019; pp. 843–849.
33. Vitón, R.; Castillo, A.; Lopes Tixeira, T. *AGTECH: Agtech Innovation Map in Latin America and the Caribbean*; Inter-American Development Bank: Washington, DC, USA, 2019.
34. Reichardt, M.; Jürgens, C.; Klöble, U.; Hüter, J.; Moser, K. Dissemination of Precision Farming in Germany: Acceptance, Adoption, Obstacles, Knowledge Transfer and Training Activities. *Precis. Agric.* **2009**, *10*, 525–545. [CrossRef]
35. Maciejczak, M.; Faltmann, J. Assessing Readiness Levels of Production Technologies for Sustainable Intensification of Agriculture. *Apstract* **2018**, *12*, 47–52. [CrossRef]
36. Pedersen, M.S.; Ferguson, B.R.; Lark, A.M. Comparison of Producer Adoption of Precision Agriculture Practices in Denmark, the United Kingdom and the United States. *SJFI–Working Paper No. 2* **2001**, *17*, 1–38.
37. Lowenberg-DeBoer, J.; Erickson, B. Setting the Record Straight on Precision Agriculture Adoption. *Agron. J.* **2019**, *111*, 1552–1569. [CrossRef]
38. Cavallo, E.; Ferrari, E.; Bollani, L.; Coccia, M. Attitudes and Behaviour of Adopters of Technological Innovations in Agricultural Tractors: A Case Study in Italian Agricultural System. *Agric. Syst.* **2014**, *130*, 44–54. [CrossRef]
39. Groher, T.; Heitkämper, K.; Walter, A.; Liebisch, F.; Umstätter, C. Status Quo of Adoption of Precision Agriculture Enabling Technologies in Swiss Plant Production. *Precis. Agric.* **2020**, *21*, 1327–1350. [CrossRef]
40. Vrochidou, E.; Oustadakis, D.; Kefalas, A.; Papakostas, G.A. Computer Vision in Self-Steering Tractors. *Machines* **2022**, *10*, 129. [CrossRef]
41. Fruhwirtova, E. Žádné Sci-Fi, Zemědělství 4.0 Se Stává Realitou [No More Sci-Fi, Agriculture 4.0 Is Becoming a Reality]. Available online: https://zazijzemedelstvi.cz/clanky/zadne-sci-fi-zemedelstvi-40-se-stava-realitou:18/ (accessed on 5 February 2022).
42. Schütze, A.; Helwig, N.; Schneider, T. Sensors 4.0–Smart Sensors and Measurement Technology Enable Industry 4.0. *J. Sens. Sens. Syst.* **2018**, *7*, 359–371. [CrossRef]
43. Vlasov, A.I.; Grigoriev, P.V.; Krivoshein, A.I.; Shakhnov, V.A.; Filin, S.S.; Migalin, V.S. Smart Management of Technologies: Predictive Maintenance of Industrial Equipment Using Wireless Sensor Networks. *JESI* **2018**, *6*, 489–502. [CrossRef]
44. Pedersen, S.R. Smart Farming. Available online: https://goexplorer.org/smart-farming/ (accessed on 10 February 2022).
45. Vrchota, J.; Rehor, P. *Influence of Strategic Management on the Importance of Crises in Farms in the Czech Republic*; Kapounek, S., Krutilova, V., Eds.; Mendel Univ Brno: Brno, Czech Republic, 2017; ISBN 978-80-7509-499-5.
46. Hurst, W.; Mendoza, F.R.; Tekinerdogan, B. Augmented Reality in Precision Farming: Concepts and Applications. *Smart Cities* **2021**, *4*, 1454–1468. [CrossRef]
47. Sishodia, R.P.; Ray, R.L.; Singh, S.K. Applications of Remote Sensing in Precision Agriculture: A Review. *Remote Sensing* **2020**, *12*, 3136. [CrossRef]
48. Pech, M.; Vrchota, J.; Bednář, J. Predictive Maintenance and Intelligent Sensors in Smart Factory: Review. *Sensors* **2021**, *21*, 1470. [CrossRef]

49. Teucher, M.; Thürkow, D.; Alb, P.; Conrad, C. Digital In Situ Data Collection in Earth Observation, Monitoring and Agriculture—Progress towards Digital Agriculture. *Remote Sens.* **2022**, *14*, 393. [CrossRef]
50. Temmen, N.; Schilling, J. *Smart Farming Technology in Japan and Opportunities for EU Companies*; EU-Japan Centre for Industrial Cooperation: Brussel, Belgium, 2021.
51. Vrchota, J.; Řehoř, P. Project Management and Innovation in the Manufacturing Industry in Czech Republic. *Procedia Comput. Sci.* **2019**, *164*, 457–462. [CrossRef]
52. Kharel, T.P.; Ashworth, A.J.; Owens, P.R. Linking and Sharing Technology: Partnerships for Data Innovations for Management of Agricultural Big Data. *Data* **2022**, *7*, 12. [CrossRef]
53. Chumnumporn, K.; Jeenanunta, C.; Komolavanij, S.; Saenluang, N.; Onsri, K.; Fairat, K.; Itthidechakhachon, K. The Impact of IT Knowledge Capability and Big Data and Analytics on Firm's Industry 4.0 Capability. *Proceedings* **2020**, *39*, 22. [CrossRef]
54. McAfee, A.; Brynjolfsson, E. Big Data: The Management Revolution. *Harv. Bus. Rev.* **2012**, *90*, 60–68.
55. Pech, M.; Vrchota, J. The Product Customisation Process in Relation to Industry 4.0 and Digitalization. *Processes* **2022**, *10*, 539. [CrossRef]
56. Abad, I.; Cerrada, C.; Cerrada, J.A.; Heradio, R.; Valero, E. Managing RFID Sensors Networks with a General Purpose RFID Middleware. *Sensors* **2012**, *12*, 7719–7737. [CrossRef]
57. Huang, G.Q.; Zhang, Y.F.; Chen, X.; Newman, S.T. RFID-Enabled Real-Time Wireless Manufacturing for Adaptive Assembly Planning and Control. *J. Intell. Manuf.* **2008**, *19*, 701–713. [CrossRef]
58. Aslan, M.F.; Durdu, A.; Sabanci, K.; Ropelewska, E.; Gültekin, S.S. A Comprehensive Survey of the Recent Studies with UAV for Precision Agriculture in Open Fields and Greenhouses. *Appl. Sci.* **2022**, *12*, 1047. [CrossRef]
59. Velusamy, P.; Rajendran, S.; Mahendran, R.K.; Naseer, S.; Shafiq, M.; Choi, J.-G. Unmanned Aerial Vehicles (UAV) in Precision Agriculture: Applications and Challenges. *Energies* **2022**, *15*, 217. [CrossRef]
60. Nakrošienė, A.; Bučiūnienė, I.; Goštautaitė, B. Working from Home: Characteristics and Outcomes of Telework. *IJM* **2019**, *40*, 87–101. [CrossRef]
61. Fernández-Caramés, T.M.; Blanco-Novoa, O.; Froiz-Míguez, I.; Fraga-Lamas, P. Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability Applications in Big Data-Driven Supply Chain Management. *Sensors* **2019**, *19*, 2394. [CrossRef] [PubMed]
62. Radočaj, D.; Plaščak, I.; Heffer, G.; Jurišić, M. A Low-Cost Global Navigation Satellite System Positioning Accuracy Assessment Method for Agricultural Machinery. *Appl. Sci.* **2022**, *12*, 693. [CrossRef]
63. Modrak, V.; Soltysova, Z.; Poklemba, R. Mapping Requirements and Roadmap Definition for Introducing I 4.0 in SME Environment. In *Advances in Manufacturing Engineering and Materials*; Hloch, S., Klichová, D., Krolczyk, G.M., Chattopadhyaya, S., Ruppenthalová, L., Eds.; Springer International Publishing: Cham, Germany, 2019; pp. 183–194. ISBN 978-3-319-99352-2.
64. Shoaib, M.; Bosch, S.; Incel, O.; Scholten, H.; Havinga, P. Fusion of Smartphone Motion Sensors for Physical Activity Recognition. *Sensors* **2014**, *14*, 10146–10176. [CrossRef] [PubMed]
65. Redden, R. Genetic Modification for Agriculture—Proposed Revision of GMO Regulation in Australia. *Plants* **2021**, *10*, 747. [CrossRef] [PubMed]
66. Czech Statistical Office Businesses by Principal Activity. Available online: https://vdb.czso.cz/vdbvo2/faces/en/shortUrl?su=2f1468c8 (accessed on 10 February 2022).
67. Witte, R.S.; Witte, J.S. *Statistics*, 12th ed.; Wiley: Hoboken, Hudson, 2016.
68. Lind, A.D.; Marchal, G.W.; Wathen, A.S. *Basic Statistics for Business & Economics*, 9th ed.; McGraw-Hill Education: New York, NY, USA, 2018.
69. European Commission The Digitisation of the European Agricultural Sector. Available online: https://digital-strategy.ec.europa.eu/en/policies/digitisation-agriculture (accessed on 10 February 2022).
70. Institute of Agricultural Economics and Information. *Zpráva o Stavu Zemědělství ČR Za Rok 2020: Zelená Zpráva [State of Agriculture Report 2020: Green Report]*; Ministry of Agriculture of the Czech Republic: Prague, Czech Republic, 2020.
71. Smolkova, B.; Dusinska, M.; Gabelova, A. Epigenetic Effects of Nanomaterials. In *Encyclopedia of Environmental Health*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 678–685. ISBN 978-0-444-63952-3.
72. Jedlicka, M. Precizní Zemědělství v Chovech Zvířat [Precision Agriculture in Animal Farming]. Available online: https://naschov.cz/precizni-zemedelstvi-v-chovech-zvirat/ (accessed on 14 February 2022).
73. Balafoutis, A.T.; Beck, B.; Fountas, S.; Tsiropoulos, Z.; Vangeyte, J.; van der Wal, T.; Soto-Embodas, I.; Gómez-Barbero, M.; Pedersen, S.M. Smart Farming Technologies–Description, Taxonomy and Economic Impact. In *Precision Agriculture: Technology and Economic Perspectives*; Pedersen, S.M., Lind, K.M., Eds.; Progress in Precision Agriculture; Springer International Publishing: Cham, Germany, 2017; pp. 21–77. ISBN 978-3-319-68713-1.