Awareness and Assessment of the Advantages of Smart Farming:

An Analysis of Farmers in the EU and the USA

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Advised by **Prof. Dr. agr. Habil. Heinz Bernhardt**
Chair of Agriculture Systems Engineering TUM
Prof. Dr. Leon Schumacher
Department Chair, Agricultural and Biosystems Engineering NDSU

Supervisor **Prof. Dr. Agr. Habil. Heinz Bernhardt**
Chair of Agriculture Systems Engineering TUM

Submitted by Christina Sebald
[redacted]

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Abstract

The agricultural sector is undergoing significant transformation, driven by adopting smart farming technologies, collectively called Agriculture 4.0. Precision, smart, and digital farming innovations promise to enhance agriculture productivity, efficiency, and sustainability. Historically, the European Union (EU) and the United States (USA) have had similar agricultural sector developments and are world-leading regions in agriculture production. This thesis investigates the awareness, adoption, and perceived benefits and criticism of smart farming technologies among EU and USA farmers. Through comprehensive surveys conducted across both regions, this study evaluates the extent to which these technologies are utilized, the challenges faced in their implementation, and the information channels farmers rely on to learn about new advancements. The analysis reveals key differences and similarities in the adoption rates and perceptions of smart farming between EU and USA farmers, highlighting the role of regional policies, infrastructure, and educational outreach in shaping these trends. The findings underscore the critical need for tailored strategies to promote smart farming adoption, addressing region-specific challenges such as internet connectivity and access to information. Ultimately, this research contributes to a deeper understanding of how smart farming can be optimized to meet the diverse needs of farmers across major agricultural regions.

Zusammenfassung

Der Agrarsektor befindet sich in einem bedeutenden Wandel, der durch die Einführung von Smart-Farming-Technologien vorangetrieben wird, die zusammenfassend als Landwirtschaft 4.0 bezeichnet werden. Innovationen in den Bereichen Präzisions-, Smart- und Digital Farming versprechen, die Produktivität, Effizienz und Nachhaltigkeit der Landwirtschaft zu steigern. Historisch gesehen haben die Europäische Union (EU) und die Vereinigten Staaten (USA) eine ähnliche Entwicklung im Agrarsektor durchlaufen und gehören zu den weltweit führenden Regionen in der landwirtschaftlichen Produktion. Diese Arbeit untersucht das Bewusstsein, die Akzeptanz sowie die wahrgenommenen Vorteile und Kritikpunkte von Smart-Farming-Technologien unter Landwirten in der EU und den USA. Durch umfassende Umfragen in beiden Regionen bewertet diese Studie das Ausmaß der Nutzung dieser Technologien, die Herausforderungen bei ihrer Implementierung und die Informationskanäle, auf die sich Landwirte verlassen, um über neue Entwicklungen informiert zu bleiben. Die Analyse zeigt wesentliche Unterschiede und Gemeinsamkeiten in den Adoptionsraten und Wahrnehmungen von Smart Farming zwischen Landwirten in der EU und den USA auf und unterstreicht die Rolle von regionalen Politiken, Infrastrukturen und Bildungsinitiativen bei der Gestaltung dieser Trends. Die Ergebnisse verdeutlichen den kritischen Bedarf an maßgeschneiderten Strategien zur Förderung der Einführung von Smart Farming, die regionalspezifische Herausforderungen wie Internetkonnektivität und Zugang zu Informationen berücksichtigen. Letztlich trägt diese Forschung zu einem tieferen Verständnis darüber bei, wie Smart Farming optimiert werden kann, um den unterschiedlichen Bedürfnissen von Landwirten in wichtigen Agrarregionen gerecht zu werden.

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1. Introduction and problem definition

Agricultural practice has always been in a state of flux. Since ancient times, crop rotations, irrigation systems, and plowing systems, for example, have been redeveloped through the centuries. Compared to the urban industry, the technical changes came slowly. However, focusing on modern agricultural practices, revolutionary changes have been made since the 19th century in the advanced industrial regions, especially Europe and the United States of America (USA). Inventions in selective breeding, crop rotations and cultivation, bioengineering, chemistry, engineering, and many more sections were made to create the high-productivity agriculture of today. In Engineering, the most significant inventions were McCormick's Reaper, the sulky steel plow, steam engines, gasoline-powered engines, the thresher, combined harvester-threshers, general-purpose tractors, rubber tires, and hydraulic implement lift with draft control (WIX 2018; MOORE 2022). Improvements in those technologies, as well as new and additional ones, are ongoing to make agriculture more productive and sustainable nowadays (EVENSON 1991; VAN DER VEEN 2010; BLAKENEY 2022). Those inventions and the adaption of those transformed agriculture from a way of life to a specialized and mechanized business with increasing yields and trading capabilities over the last 150 years, on the one hand, and also high investment costs, on the other hand (FRED W. KOHLMEYER UND FLOYD L. HERUM 1961)

Historically, the United States of America and the European Countries, and nowadays the European Union (EU), have always had a considerable interest in the trade of agricultural products. Twenty years ago, in 2004, the United States Department of Agriculture (USDA) published an agriculture and trade report about "U.S.-EU Food and Agriculture Comparisons" (MARY ANNE NORMILE UND SUSAN LEETMAA 2004). This report aims to highlight the similar and distinct aspects of their agriculture sectors and policies. The focus is on general statistical facts about macro and socioeconomic factors, agriculture in the economy, farm structures, agricultural output, trade, commodity policy of the USA and EU, risk management tools, agriculture productivity, consumption trends, and environmental protection. This was of interest because both regions were two of the largest producing, consuming, and trading entities for agricultural products, which had bilateral trade relationships on the one hand and were competitors on the agricultural market on the other hand.

In 2004, 15 countries joined the EU already. Since that time, not only has the number of member countries of the EU enlarged to 27 (EU 27) (EUROPEAN UNION 2024a), but also macro and socioeconomic factors like labor shortage, agriculture in the economy, farm structures, agricultural output, trade, commodity policy of the USA and EU, management tools, agriculture productivity, consumption trends, regulations have been changed in the past 20 years in both regions (SCOTT 2024; USDA FOREIGN AGRICULTURAL SERVICE 2024a; MCFADDEN J. ET AL. 2023; LOWENBERG-DEBOER 1998; GABRIEL UND GANDORFER 2023; Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems 2022; INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) 2022).

Nevertheless, the United States and the EU27 are still leading crop and livestock production regions with different trading partnerships and collaborations (KAUFMANN 2024; DOHLMAN ET AL. 2024). The EU is the USA's fifth biggest export market for agricultural products (INTERNATIONAL TRADE ADMINISTRATION 2024). Since November 2021, the Cooperation Platform on Agriculture (CPA) has arranged and aimed to enhance the collaboration and dialogue between the European Commission’s Directorate-General for Agriculture and Rural Development and the United States Department of Agriculture (USDA). The CPA focuses on sustainability, climate, agri-food exchanges, soil health, mitigation of greenhouse gas emissions, communication and food systems, and resilience and adaption. (EUROPEAN COMMISSION’S DIRECTORATE-GENERAL FOR AGRICULTURE 2021; USDA FOREIGN AGRICULTURAL SERVICE 2024b). Not only did demographic, economic, political, and environmental changes lead to an ongoing partnership and collaboration in agriculture trade and information exchange between the US and EU27. Both regions are some of the biggest producers, exporters, and importers of diverse agricultural goods worldwide, and many problems and challenges for agriculture are global and need to be faced united and interdisciplinary (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) 2022).

One way to address agriculture's challenges and increase productivity and efficiency is through the development of 'Agriculture 4.0' (DA SILVEIRA ET AL. 2021). This term encompasses precision-, smart- and digital farming technologies, mainly originating in Industry 4.0 technology and heralding a new era of technical agricultural revolution (KLERKX ET AL. 2019; BERNHARDT ET AL. 2021). The history of Precision Agriculture, now over 30 years old, has seen continuous development and improvement, with new innovative technologies being developed and launched for the agricultural market. The 'Agriculture 4.0' revolution offers a beacon of hope for the future of agriculture, promising increased productivity, efficiency, and sustainability (HANEKLAUS ET AL. 2016; PEDERSEN UND KIM MARTIN LIND 2018). To reach these social, economic, and ecologically sustainable agriculture goals and face future challenges for agriculture, farmers, especially in the most prominent and highly productive agricultural regions, need to adapt to ‘Agriculture 4.0’ technology. Compared to other industries, Industry 4.0 technologies are slowly adapting to agriculture, although there were many beneficial use cases, such as harvest technology, dairy farming, and more (BERNHARDT ET AL. 2021; KRAFT ET AL. 2022).

This leads to what drives and prevents farmers from adopting Agriculture 4.0 technologies, especially in the EU 27 and the USA. Do farmers see advantages in Agriculture 4.0 technologies? In this context, it is also important to determine where farmers get information about these technologies and how often they are interested in educating themselves. Furthermore, to promote the adoption of Agriculture 4.0 technologies, the needs of the farmers and major critics need to be known for the improvement of these technologies. Although many surveys were conducted and much research is going on in this context, there is still a lack of knowledge of what farmers feel about Agriculture 4.0 technologies.

2. State of the art and knowledge

For a better understanding and classification of why it's essential to focus on and compare the USA and the EU 27 regarding Agriculture 4.0, the following sections highlight the significant characteristics of agriculture production facts and the framework farmers have to deal with in agriculture in the United States and the European Union (EU27). Furthermore, the focus is on smart farming technologies, such as drones for crop monitoring, automated tractors for precision planting, and data analytics for yield prediction, their application areas, and their adaptation in both regions.

2.1. Agriculture in the European Union

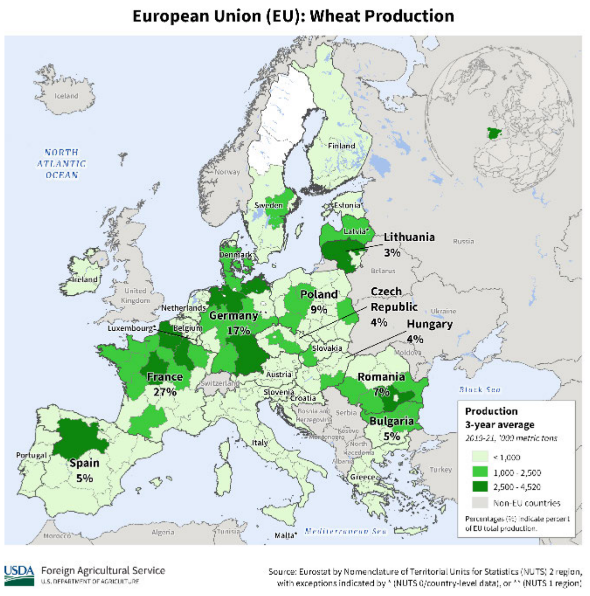
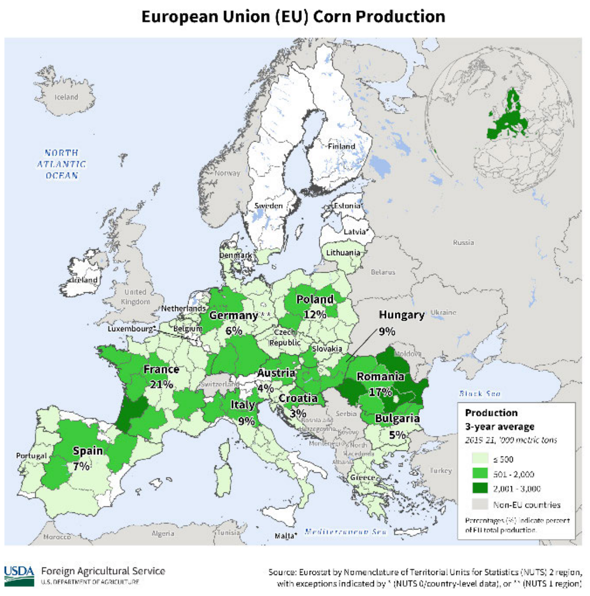
To understand the structure of agriculture systems and the agriculture policy of the European Union, what makes it unique and one of the biggest agricultural traders must be explained. The European Union is a unique concept worldwide. It is a political confederation of 27 states nowadays, starting with the foundation of the European Coal and Steel Community in 1951, which became 1958 the European Economic Community (EEC). This unique concept, initially formed by Belgium, France, Germany, Italy, Luxembourg, and the Netherlands, agreed to a common agricultural policy (CAP) in 1962. Since 1993, the European Union has officially existed. Over the years, the EU has grown to 27 member states with 24 official languages. (EUROPEAN UNION 2024a; EUROPEAN COMMISSION 2024b; EUROPEAN COMMISSION UND AGRICULTURE AND RURAL DEVELOPMENT 2024b)

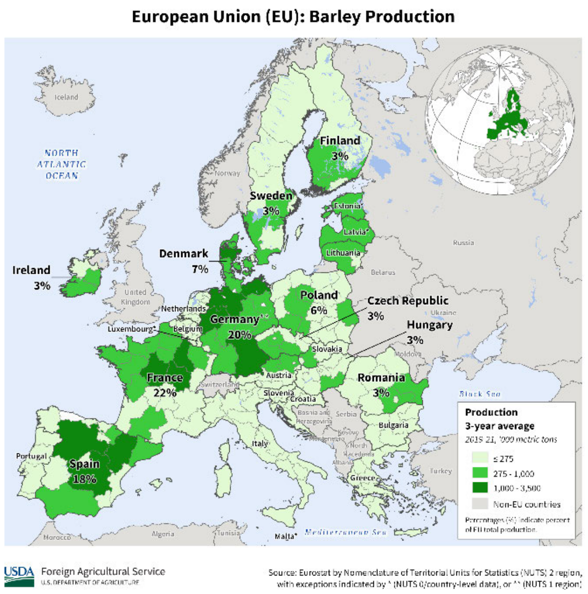
Farm and field sizes and structures are diverse and heterogeneous depending on the landscape, soil, and historical and cultural background of each region of the EU. 157 million hectares of land were used for agriculture production in 2020, corresponding to 38% of the land area of the EU. Only 5,6% of the European farmers were younger than 35 (EUROSTAT).

2.1.1. Crop Production in the EU27

The variety of crop production in Europe is broad and depends strongly on the region and climate. One of the leading agricultural branches is cereals. The main crops grown are wheat, corn, and barley, as shown in Table 1. Furthermore, potatoes, sugar beets, oil seeds, especially rape seeds and sunflower seeds, fruits like apples, vegetables, grapes for wine, olives, and hops play, depending on the region, a significant role in Europe agriculture production.

Table 1 Major crop production and location in the European Union (USDA FOREIGN AGRICULTURAL SERVICE 2024d; EDWARD COOK)

Crop Production	Average yield between 2019-2023 in 1.000 tons	Main producing regions in the EU
	134.624	1. France 2. Germany 3. Poland 4. Romania 5. Bulgaria
	63.927	1. France 2. Poland 3. Romania 4. Italy 5. Germany

	52.233	1. France 2. Germany 3. Spain 4. Denmark 5. Poland

2.1.2. Livestock Production in the EU27

The leading livestock-producer nations in the EU27 are Spain, France, and Germany. In total, 43,5 million tons of meat were produced in 2019. One million tons of veal, 5,9 million tons of beef, 13,3 million tons of poultry, 22,8 million tons of pork, and 0,5 million tons of sheep and goat meat were produced in 2019 in the total EU 27. While the output volumes of crops increased significantly, the output volume of pigs and cattle meat decreased. (EDWARD COOK). The EU 27 is the second largest pork producer, with 18% of the world's production, behind China (50% of world pork production), and the fourth largest producer of chicken meat and beef, each with 11% of world production. (USDA FOREIGN AGRICULTURAL SERVICE 2024e)

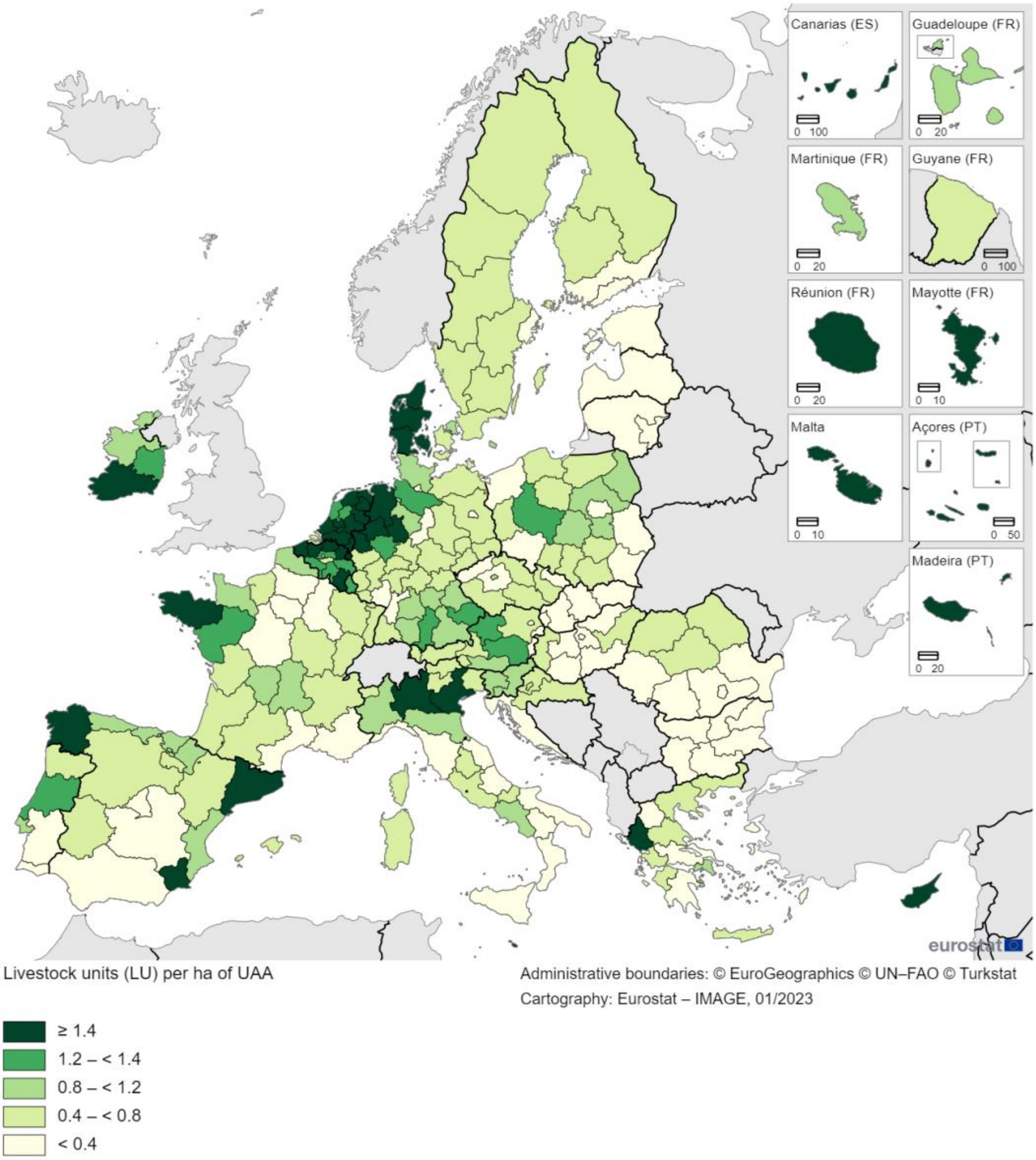
The EU27 is the world's largest milk producer, with 31% Global production (M. SHAHBANDEH 2024; USDA FOREIGN AGRICULTURAL SERVICE 2024e). The leading milk and dairy products producer nations are Germany, France, Netherlands, Poland, and Italy. Germany produced 2019 over 30 million tons of milk, which is twice the volume of Italy and a fifth of the total milk production by dairy of the EU27 (EDWARD COOK).

As seen in Figure 1, the distribution of livestock production is concentrated in a few regions with a high density of livestock. The Netherlands has the highest livestock density, with 3.5 livestock units per hectare in 2020. The total average density of livestock in the EU 27 was

0,7 in 2020. Between 2010 and 2020, the average density fell by 4.0%, reflecting a decrease in livestock farmers (EUROSTAT 2024).

Livestock density

(livestock units per hectare of utilised agricultural area, EU NUTS 2 regions, 2020)



Eurostat (online data code: ef_lsk_main for LSU, ef_m_farmleg for UAA total)

Figure 1 Livestock density in the EU 27 (EUROSTAT 2024)

2.1.3. Common Agriculture Policy

As mentioned, the CAP was launched in 1962 during the time of the ECC as a partnership between agriculture and society and between Europe and its farmers. Today, in the European Union, CAP is the common agriculture policy for all member states to support farmers and improve agricultural productivity to ensure a stable supply of affordable food. Further aims of the CAP are to support European Farmers to make a reasonable living, to tackle climate change and support the sustainable management of natural resources, to maintain rural areas and landscapes across the EU, and to keep the rural economy alive by promoting jobs in farming: Agri-food industries and associated sectors. CAP is managed and funded from the EU's budget at a European level and is about 38% of the EU's budget. The fund is split into two pillars. One is the direct payments to farmers (European Agricultural Guarantee Fund (EAGF) with over 70% of the budget, and the other is the European Agricultural Fund for Rural Development (EAFRD). The farmer's payment amount depends on each farm and its sustainability management. The new CAP 2023-2027 strategic plan includes the European Green Deal ambitions, the Farm to Fork Strategy, and biodiversity strategies (EUROPEAN COMMISSION UND AGRICULTURE AND RURAL DEVELOPMENT 2024b, 2024a).

Many statutory provisions exist in the context of agriculture to regulate the CAP (EUROPEAN UNION 2024b). Some requirements regulate animal transportation and animal husbandry, including animal welfare, food security and safety, bioengineering, ecological farming, nitrate applications, manure application, limit nitrogen values for water bodies, the permitted plant protection products and applications, and much more. Every EU member country must follow those resolutions and have the opportunity to design additional ones (EUROPEAN COMMISSION 2024c).

2.1.4. Smart Farming in the EU27

Smart Farming technologies are seen as a support system for farmers facing challenges in an environmentally friendly context to promote sustainable agriculture and in an economic context to promote farm management strategies and development. The CAP 2023-2027 aims to support the digital transitions in agriculture. (BARBARA UND KRZYSTOFOWICZ 2023). The adoption of smart farming technology in the EU seems to depend on the application area, the farm size, and the farm focus. Lowenberg and Erickson stated in 2019 that, for example, guidance technology is less used than in other industrial regions worldwide. The application of variable rate technology is more adapted than in countries like the USA and Australia (LOWENBERG-DEBOER UND ERICKSON 2019). There is no official data from the EU about adopting smart farming technologies. Each country or state of the EU27 examines the state of the art by itself, for example, in Bavaria and France (LACHIA ET AL. 2019; GABRIEL UND GANDORFER 2023, 2022).

To close this lack of knowledge, Thünen Institut" Germany started a survey about the adaption and application of digital farming technologies on German Farms in January 2024 (THÜNEN-INSTITUT FÜR AGRARTECHNOLOGIE 2023). In 2020, an online survey by Gabriel et al. (Gabriel et al. 2021) focused on the application, adaption, and barriers to using smart farming technologies in Germany. In Bavaria, 66,8% of the farmers use at least one smart farming technology (GABRIEL UND GANDORFER 2022).

The integration on the farm, as well as the research and development of smart farming technologies, are pushed by different governmental organizations of the EU (BARBARA UND KRZYSTOFOWICZ 2023; BUNDESMINISTERIUM FÜR ERNÄHRUNG UND LANDWIRTSCHAFT (BMEL)). The EU network expansion is important in the strategies plans (BUNDESMINISTERIUM FÜR ERNÄHRUNG UND LANDWIRTSCHAFT (BMEL); BERNHARDT ET AL.).

2.2. Agriculture in the United States of America

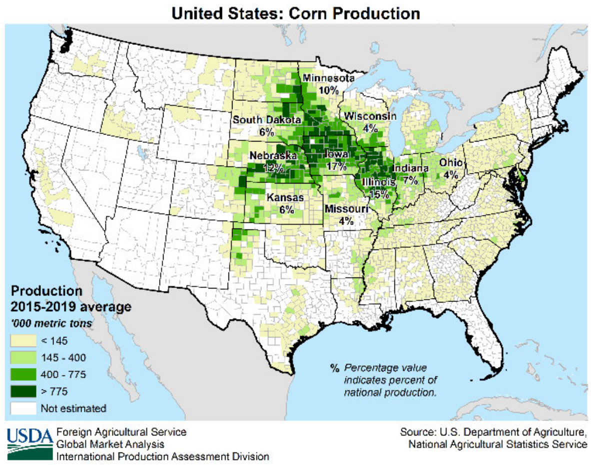
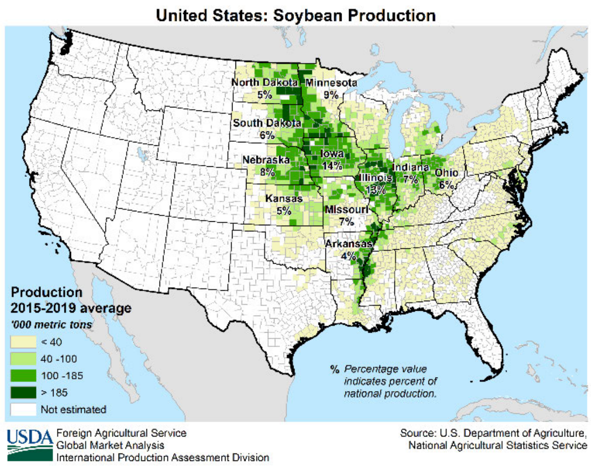
Compared to Europe's agricultural history, the history of the United States, and the settlement of the Midwest and Western parts of the United States. Nevertheless, Agricultural practices were always comparable because most settlers had European backgrounds and used the same practices as those on the old continent (HARRY C. TRELOGAN 1969).

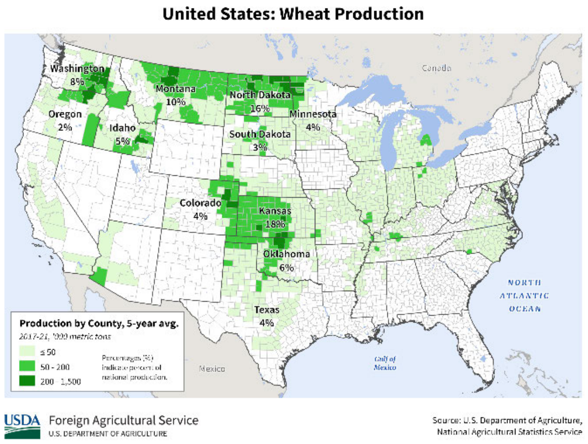
52% of the land in the United States was used as agricultural land in 2012. This corresponds to around 485.622.770 hectares. 18% is cropland, 30 % is classified as grassland pasture and range, and around 4% is grazed forestland (USDA ECONOMIC RESEARCH SERVICE 2024a). The average farm size was 446 acres in 2022 (GAO 2024) and 9% of the farmers are younger than 35 years old (USDA NATIONAL AGRICULTURAL STATISTICS SERVICE 2024)

2.2.1. Crop Production in the USA

As shown in Table 2. the top three crops produced in the United States are corn, soybean, and wheat. Corn makes a world market share of 32%, soybeans 29% and 6%. Further commodities are almonds and pistachios, primarily produced in California and the USA, producing most of them worldwide (USDA FOREIGN AGRICULTURAL SERVICE 2024e). Depending on the region, the United States offers various arable cultures like cotton, vegetables, nuts, fruits, and oil seeds. The growth depends on the region and climate and is very specialized in some regions.

Table 2 Major crop production and location in the United States (USDA FOREIGN AGRICULTURAL SERVICE 2024c)

Crop Production System	**Average yield between 2019-2023 in 1000 tons**	**Main producing regions in the USA**
	364.074	1. Iowa 2. Illinois 3. Nebraska 4. Minnesota 5. Indiana
	112.492	1. Iowa 2. Illinois 3. Nebraska 4. Indiana 5. Missouri

	48.224	1. Kansas 2. North Dakota 3. Montana 4. Washington 5. Oklahoma

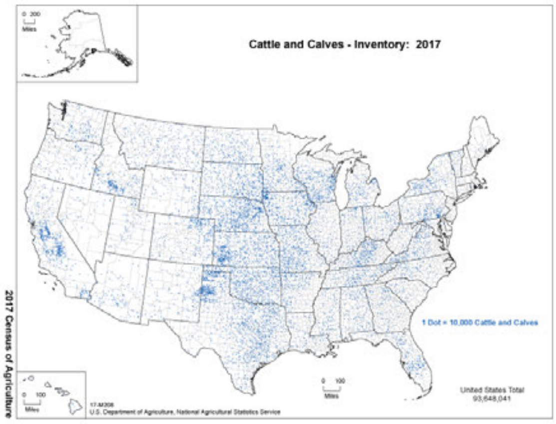
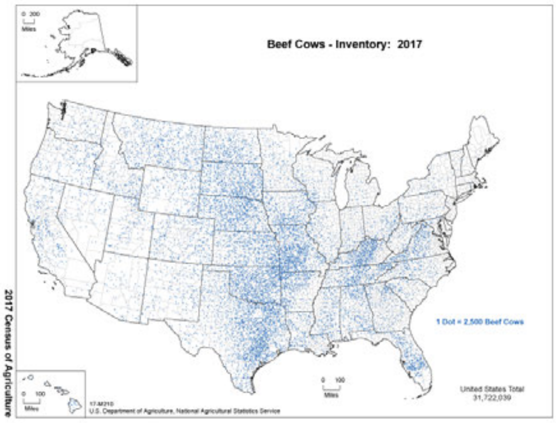
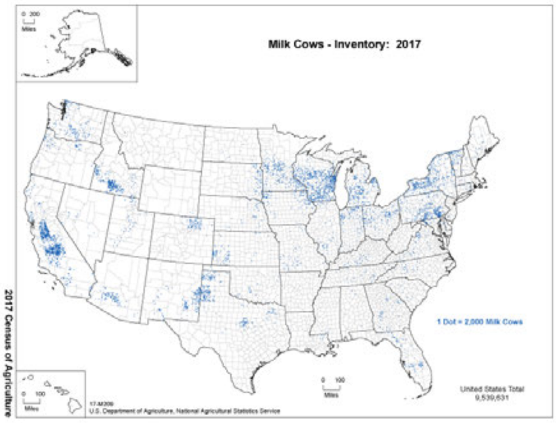
2.2.2. Livestock Production in the USA

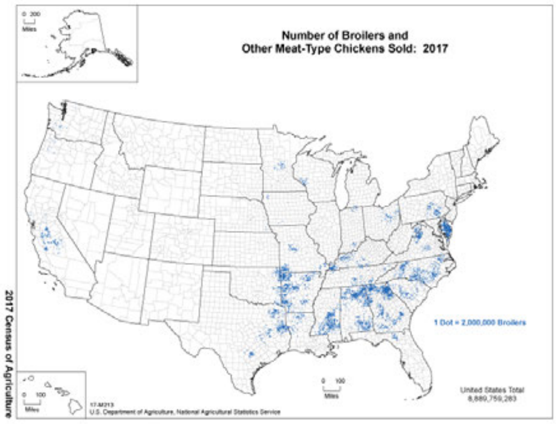
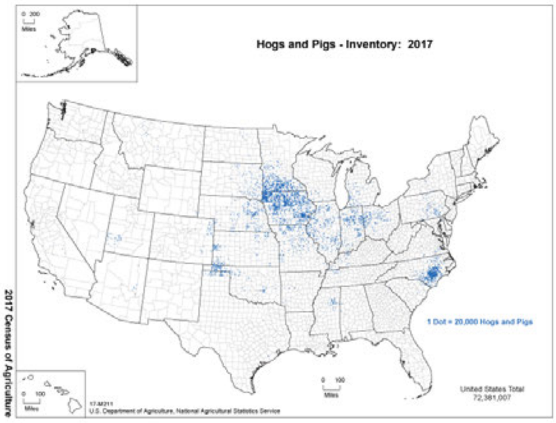
The United States produces around 47.5 million tons of meat annually. The major livestock production systems for meat are cattle, with an average beef output of 12 million tons, and chicken meat, which is 21 million tons yearly. Beef and chicken meat produced in the United States make a world market share of 20% each. This makes the USA the leading beef and chicken meat producer worldwide. Around 12,5 million tons of pork are produced by the United States, which makes it the 3rd biggest pork producer. The United States is also the second biggest dairy producer, with a world market share of 24%. (USDA FOREIGN AGRICULTURAL SERVICE 2024e).

While cattle and beef cows are produced and distributed throughout the United States, with the main focus on the states of the Midwest and Texas, milk cows, broilers, pigs, and hogs are more focused on specific regions in the US (USDA NATIONAL AGRICULTURAL STATISTICS SERVICE 2024). The exact distribution of the major livestock is shown in Table 3.

Table 3 Distribution by kind of livestock in the United States (USDA NATIONAL AGRICULTURAL STATISTICS SERVICE 2024)

Census 2017 Ag livestock	**Regions**

	The whole United States, with the main focus of the operation system in the Midwest and Texas.
	The whole United States, with the main focus of the operation system in the Midwest and Texas.
	Primarily North East around the Great Lakes and California: Wisconsin, Minnesota, Michigan, Ohio, Pennsylvania, New York, Texas, New Mexico, Arizona, California, Idaho, Colorado, Washington, Oregon, (South Dakota, Iowa, Kansas)

<table>
<tr>
<td>
</td>
<td>Mainly in the South East and California.</td>
</tr>
<tr>
<td>
</td>
<td>Only in the regions of Iowa, Minnesota, Illinois, Indiana, Ohio and North Carolina.</td>
</tr>
</table>

Most animal production is located in the whole Midwest, including Texas and specific counties of California and Florida. The livestock density is up to 1,9 head per hectare (corresponding in the following interpretation as Livestock Unit per hectare), which is seen in Figure 2.

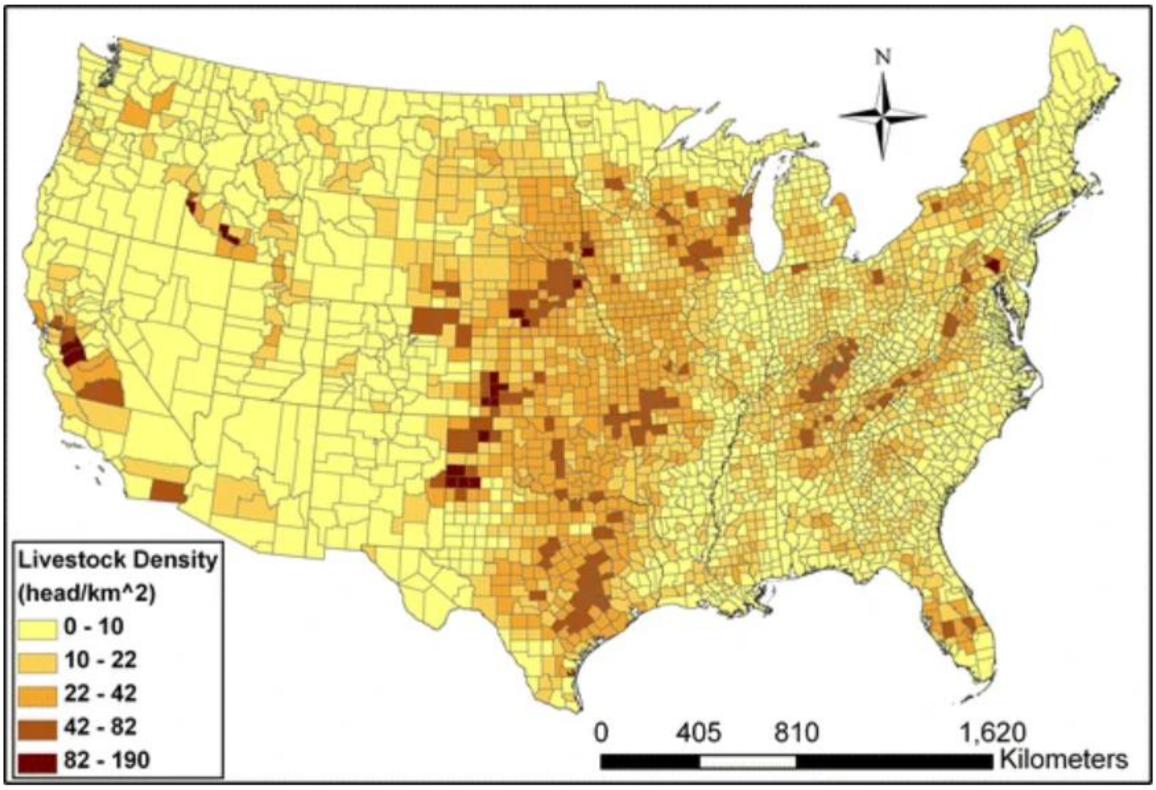


Figure 2 Livestock Density USA 2011 (KONRAD ET AL. 2011)

2.2.3. Agriculture Policy in the USA

In the United States, 34% received governmental payments in 2021. Most of them were commercial farms with over 35000$ gross cash farm income. To obtain those payments, farmers must participate in programs like the Conservation Reserve Program (CRP) (SUBEDI ET AL. 2021). Most of the USDA's budget is spent on food aid (BUNDESMINISTERIUM FÜR ERNÄHRUNG UND LANDWIRTSCHAFT (BMEL)). The most important regulation is the farm bill as an agricultural and food policy instrument. The Farm Bill aims to support America’s farmers, ranchers, and forest stewards through national safety nets, farm loans, conservation, and disaster assistance programs (USDA FOREIGN AGRICULTURAL SERVICE 2020). The USDA gives the operation frame for farmers, but depending on the State, agriculture regulations can differ.

2.2.4. Smart Farming in the USA

The adoption of precision farming technologies is mainly focused on farms in the Midwest States. In North Dakota, South Dakota, Nebraska, Iowa, and Illinois, precision farming technologies are over 50% for managing crops or livestock. This is seen in Figure 3. Corn and soybean producers mostly use precision farming technologies. Automated guidance, yield mapping, soil sampling technologies and maps, sprayer section controllers, and variable rate technologies are the most common technologies used in crop production in the USA (GAO 2024; ERICKSON 2022). Furthermore, Schimmelpfenning and Lowenberg-DeBoer found that the adaption rate of precision farming technologies is highest on large farms but is used across all farm sizes in the USA. Also, the use of variable rate technologies is higher in areas with highly heterogenous soil variability (SCHIMMELPFENNIG UND LOWENBERG-DEBOER 2020; SCHIMMELPFENNIG UND LOWENBERG-DEBOER 2021).

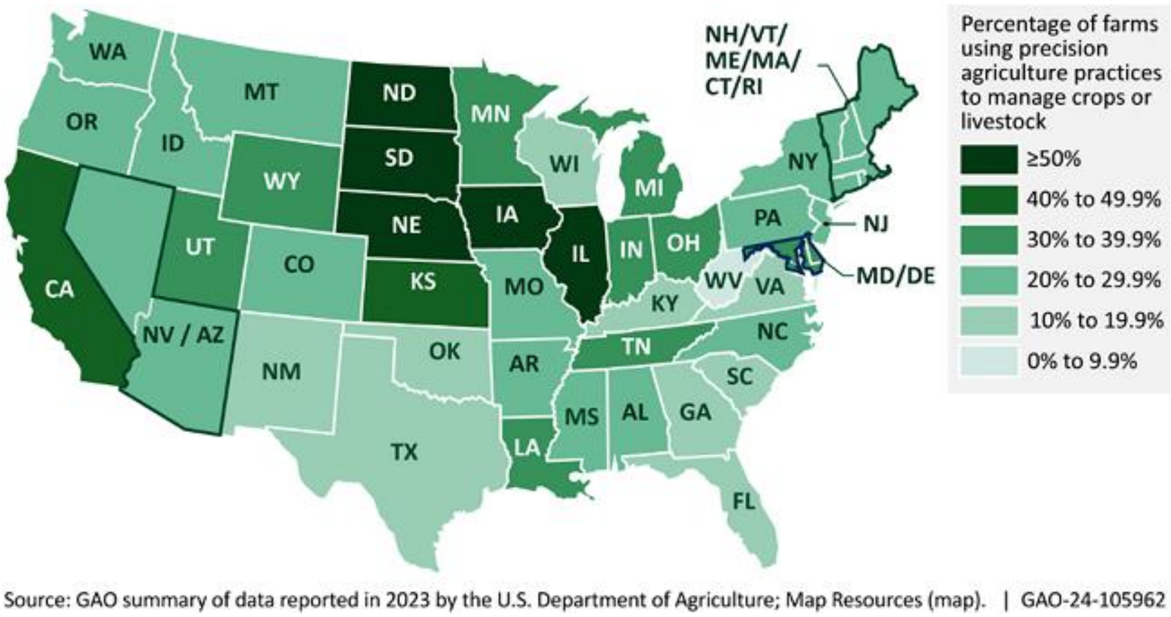


Figure 3 Adaption of Precision Livestock technologies in the USA (GAO 2024)

3. Objective

In the United States of America (USA) and the European Union (EU), the history of precision agriculture is now over 30 years old. During this period, the development of precision agriculture towards smart and digital agriculture is ongoing. However, the application and acceptance of these technologies seem rare on farms in both regions. Although there are case studies in both areas about the "Adoption of Smart Farming Technologies," there are still many uncertainties (KLERKX ET AL. 2019). For example, the feelings and needs of the farmers regarding precision, smart, and digital farming technologies are primarily unknown to companies and scientific research.

To close this lack of knowledge, this paper refers to the state of the art of smart farming in the USA and the EU.

The main objective of this thesis is to determine the farmers' awareness and acceptance of innovative farming technologies in different structured agricultural regions like the EU and the USA. The most common production systems in livestock and crop production are examined. Both regions were compared, and the differences in farm structures, land use, landscapes, Internet connectivity, etc., were elaborated. Furthermore, the assessment of innovative farming technologies and the most critical challenges for farming from the farmer's perspective were determined based on a survey among the USA and the EU.

Farmers' most essential needs and challenges in smart farming will be identified. Given the structural differences, EU and USA farmers are compared to determine possible causes.

The results were compared to similar surveys and literature review articles as well.

Furthermore, the methodology of an online survey for social sciences and socioeconomic questions will be discussed.

4. Material and Method

A literature review about the state of the art and the main differences in agriculture between the EU and the USA was conducted to close the lack of knowledge about the application, awareness, and acceptance of smart farming technologies on farms and ranches in those regions. This is shown in Chapter 2.

Furthermore, an online survey was implemented in the Midwest of the United States and the European Union. The survey compares both regions and focuses on the awareness and acceptance of smart farming technologies. This survey was designed to focus on the end-users, the farmers, and their needs and criticism according to smart farming technology. The results are shown in chapter 5.

The materials and methodologies used are explained in the following paragraphs.

4.1. Material

For the literature review, most of the information regarding differences in agriculture regulations in the USA and the EU was collected from the governments' publications. The publications and regulations by the USDA, the European Commission, and the BMLE were particularly reviewed. Furthermore, publications of the region's most prominent research institutes and universities on “digitalization in agriculture” and “application of smart farming in agriculture” were also used.

The results are given in Chapter 2 and are the basic knowledge for conducting the follow-up online surveys about the “Application and evaluation of smart farming technologies”.

A survey in German and English was conducted. The English version of the survey is called “Application and Evaluation of Smart Farming Technologies,” and the German version is called “Anwendung und Bewertung von Smart Farming Technologien”. Both were created using Microsoft® Forms® (Microsoft 365, Microsoft Corporation; Redmond, Washington, USA). In total, each survey includes 51 questions. Not every question needs to be answered by every farmer. The path and number of questions every farmer could answer depends on the previous answer given by specific questions. Therefore, the minimum number of questions for a farmer could be 16, and the maximum number for a farmer to answer could be 48. The structure of the survey is explained in detail under Section 4.2

The evaluation was conducted with Microsoft® Excel® for Microsoft 365 MSO (Version 2406 Build 16.0.17726.20078, Redmond, Washington, USA) and OriginPro® (Version 2024b, OriginLab®; Northampton, Massachusetts, USA).

4.2. Method

Figuring out the awareness, assessment, acceptance, and application of Smart Farming technologies from a farmer's perspective leads to a combination of agriculture engineering and social sciences. An online survey was chosen as the most suitable method to get feedback from farmers about this topic in different countries on different continents. Besides these advantages, surveys are a typical method for quantitative evaluations (UNIVERSITÄT LEIPZIG 2024) and a common tool for descriptive social science questions (STAINES ET AL. 2023).

As seen in Figure 4, the questionnaire was subclassified into six topics. Those topics were "1. General questions", "2. Challenges in agriculture", "3. Applied smart farming technologies", "4. General operational information on animal husbandry on your farm", "5. Applied smart farming technologies in animal husbandry" and "6. Applied smart farming technologies in crop production". The main goal during the conduction of the online survey was to keep it quick and simple for the farmers. Since the opinion of every type of farmer in the USA and EU is relevant, but not every farmer, e.g., is a livestock farmer or operates with Smart Farming technologies, the questionnaire was designed in a "branch and sector design" as seen in Figure 1. This survey design allowed for "individualization" and focused on the single farmer's operation, excluding minor relevant questions in context with the farmer's operation focus. For example, a crop farmer answered the questionnaire, and based on his answers, automatically topics 4 and 5, which were only related to livestock farming, were skipped.

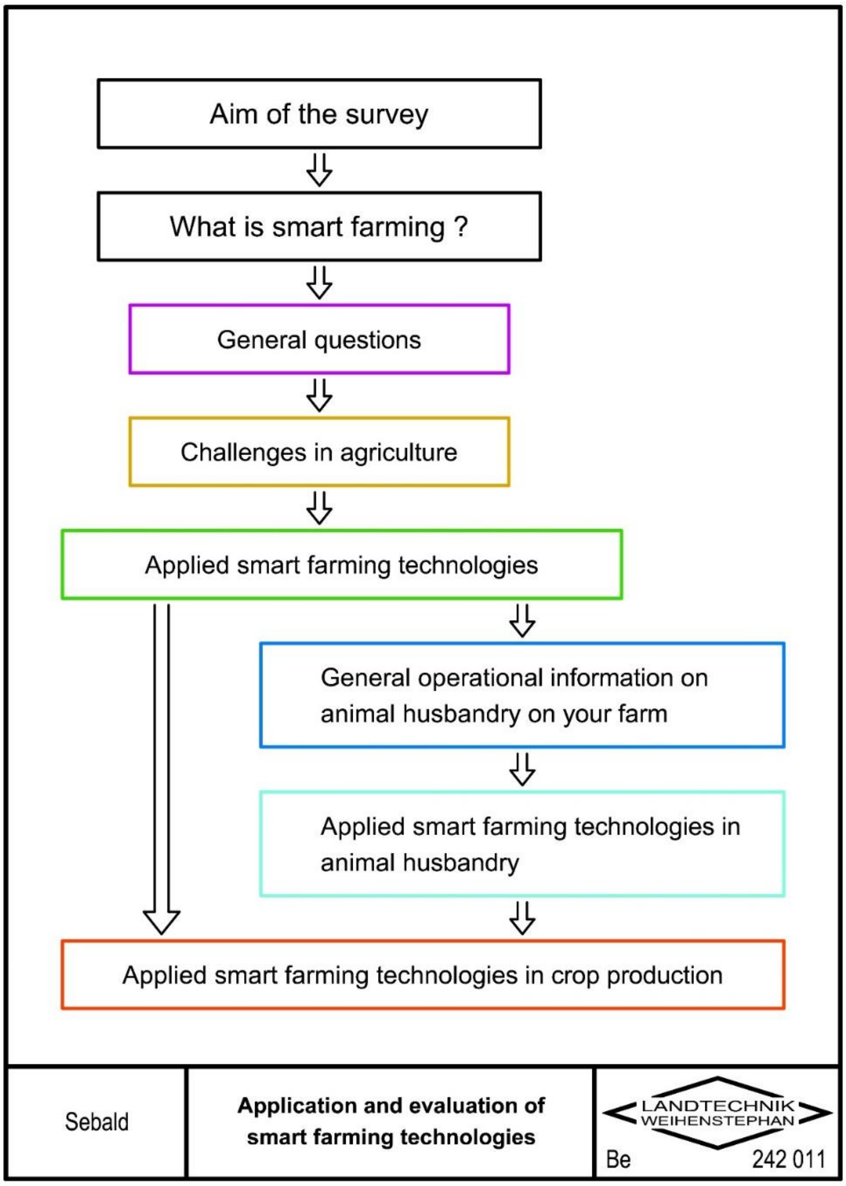


Figure 4 Structure of the questionnaire

Every participant had to answer questions 1, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 44, 45, and 46. All questions in the questionnaire, except question number 39, were closed questions and obligatory to answer if it was on the branch of the participant. 37 out of 51 were single-choice questions. In 8 out of 51 questions, the participants had to rate their satisfaction with some technologies, personally assess the most common challenges for agriculture, and common reasons for purchasing or not purchasing smart farming technology. The opportunity to give multiple answers was offered in 5 out of 51 questions. Number 39, "If you use further smart farming technologies, please write it down here. If not, please go on," was an open question and was voluntary to be filled in.

As seen in Figure 5, the first junction is directly after question number 1, whether your farm is in the United States or the EU. Because of the heterogeneous structure of the landscape, different farm focuses depend on the region and the regulations of the single states in the United States, and the state of the farm location was asked for. Also, for farmers in the EU's heterogeneous landscapes, different farm focuses depend on the region, and various regulations, depending on the countries and states, play a significant role. Therefore, the participants were asked which country of the EU27 their farm is located in. An additional question about the state was asked only if the farm is located in Germany because the main focus is on the differences between Germany and North Dakota.

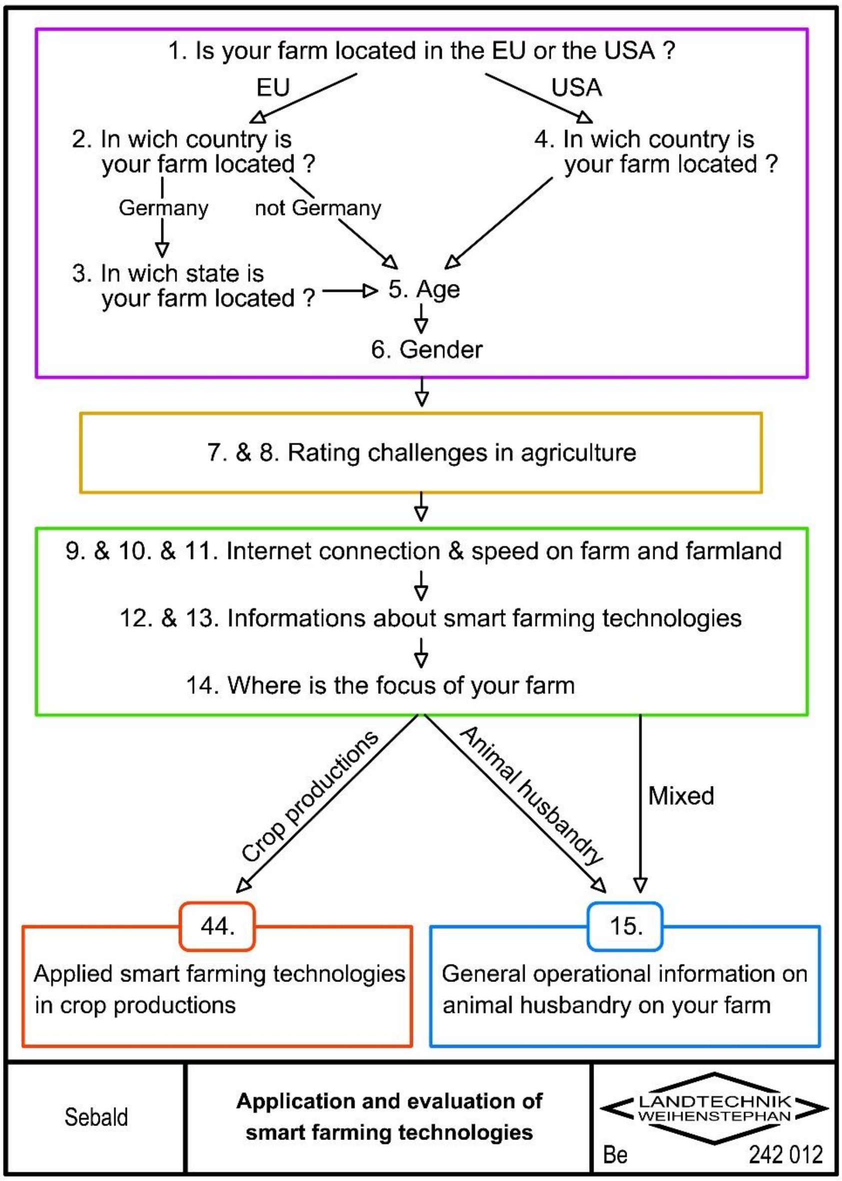


Figure 5 Detailed structure from questions 1 to 14

For categorizing the farms and splitting the livestock operations and crop operations, in question number 14, the farmers could choose the main focus of their farm between crop production and mixed and animal husbandry. As seen in Figure 5, a crop producer can skip all questions about animal husbandry and smart farming technologies in livestock and get forwarded to question number 44, seen in Figure 8.

A livestock producer and a farmer of a mixed operation get forwarded to the section of questions about “General operational information on animal husbandry on your farm”. The participating livestock farmers were asked if they work with dairy cows, cow-calf-operation, growers/stockers, finishing cattle, goats, sheep, laying hens, broiler chicken, turkey, breeding sows, or finishing pigs on their farm. All kinds of livestock were asked separately, and if they chose “Yes,” they were asked how many of these kinds of livestock were on the farm. Otherwise, the question about the number of animals was skipped. This principle is seen in Figure 6.

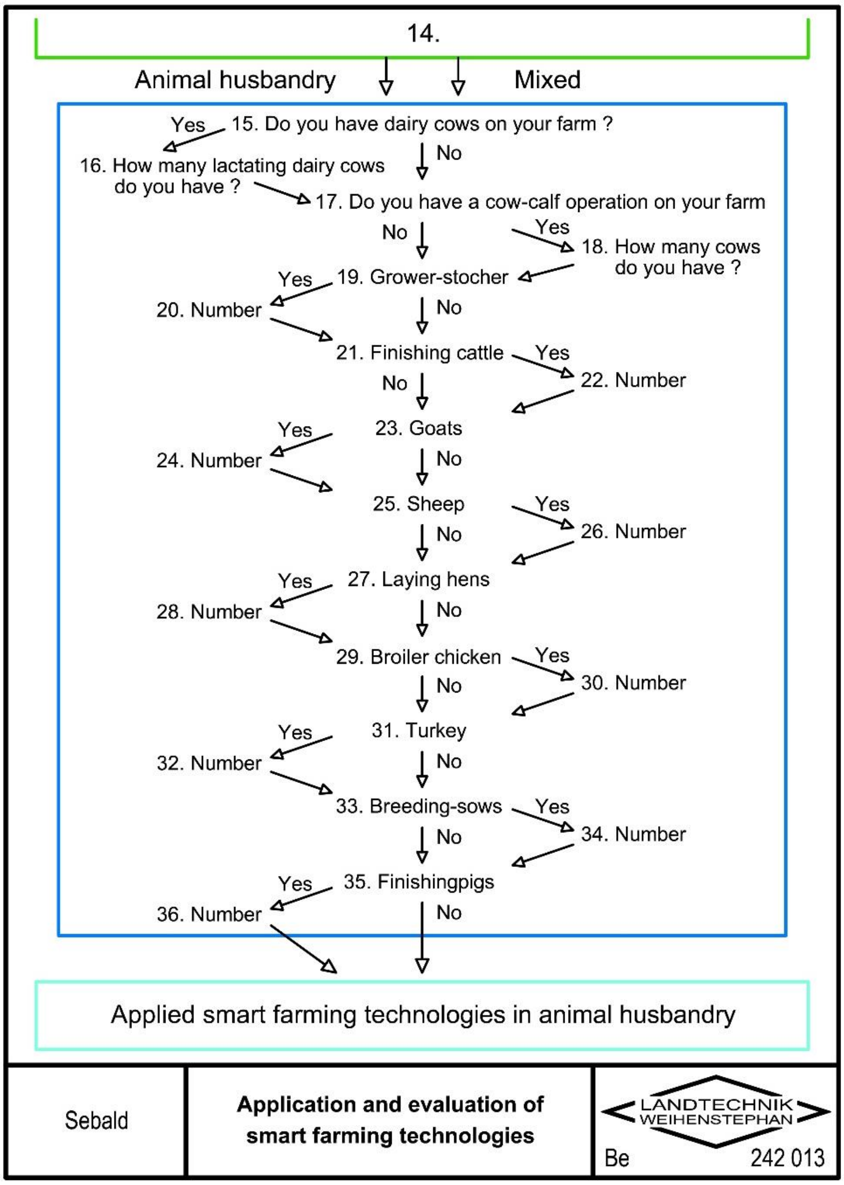


Figure 6 Detailed structure from questions 15 to 36 in the section for livestock farmers

After the participant had answered categorization questions about livestock production, questions related to the topic “Applied smart farming technologies in animal husbandry” were asked of the livestock producer. Depending on the answer to question 37, “Are smart farming technologies in use on your farm?” the farmer either had to answer one more question about “What prevents you from purchasing smart farming technologies in livestock farming?” or five more questions about the used smart livestock farming technologies, the satisfaction with it and the most critical points about it. In detail, the structure of this section is shown in Figure 7.

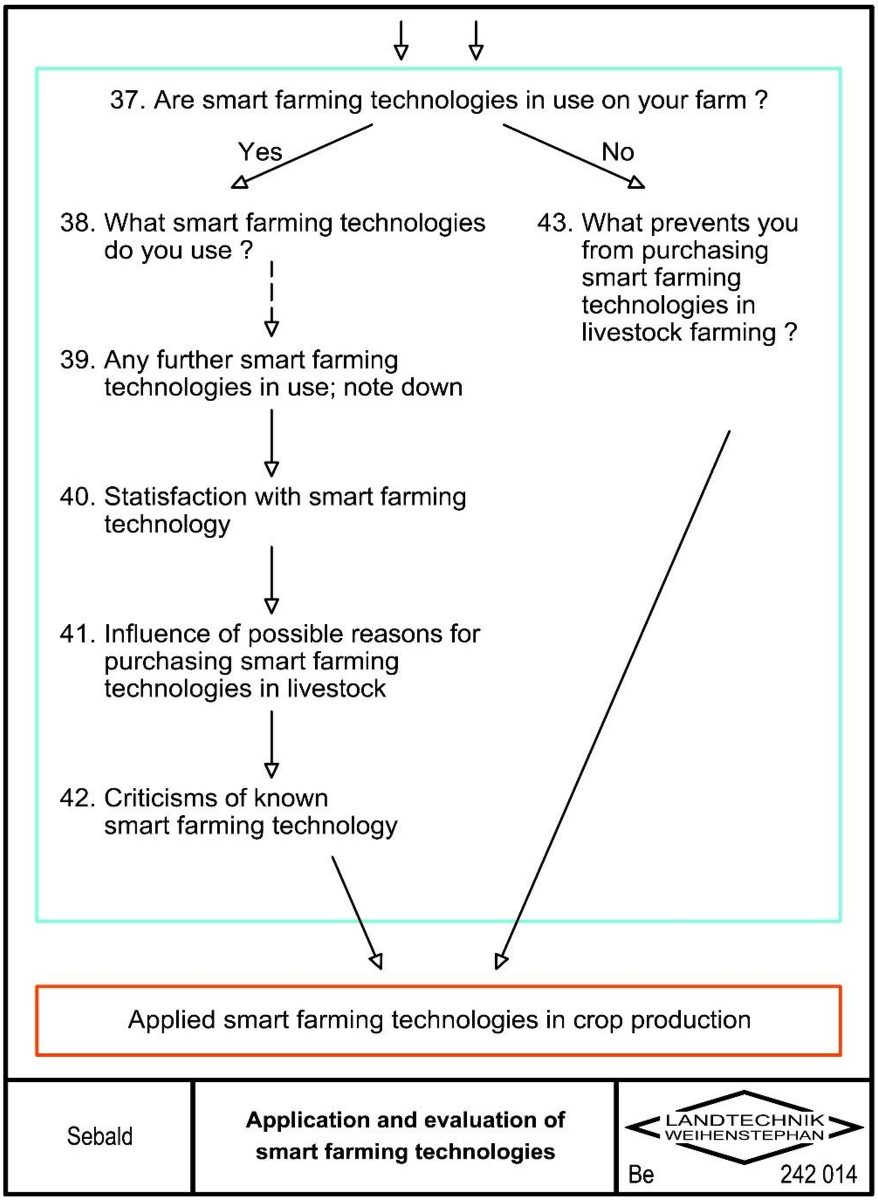


Figure 7 Detailed structure from questions 37 to 43 in the section for livestock farmers

Crop producers were forwarded after question number 14 directly to “Applied smart farming technologies”. Also, livestock producers and farmers of a mixed farm submitted to this topic after answering questions about “Applied smart farming technologies in animal husbandry”, as seen in Figure 8. The first two questions in this section were general questions to classify the farm. The questions were about the size of the farmland and a collection of the most common crops growing on the farmland.

Figuring out how standard smart farming technologies are in crop production, question number 46, “Do you use smart farming technologies in crop production?” was asked. Depending on the answer to number 46, the participant was asked which technology is used, its satisfaction, why they purchased it, and the significant critics of the technology. If no smart farming technology is used in crop production, the participants were asked about the reasons preventing them from purchasing smart farming technologies.

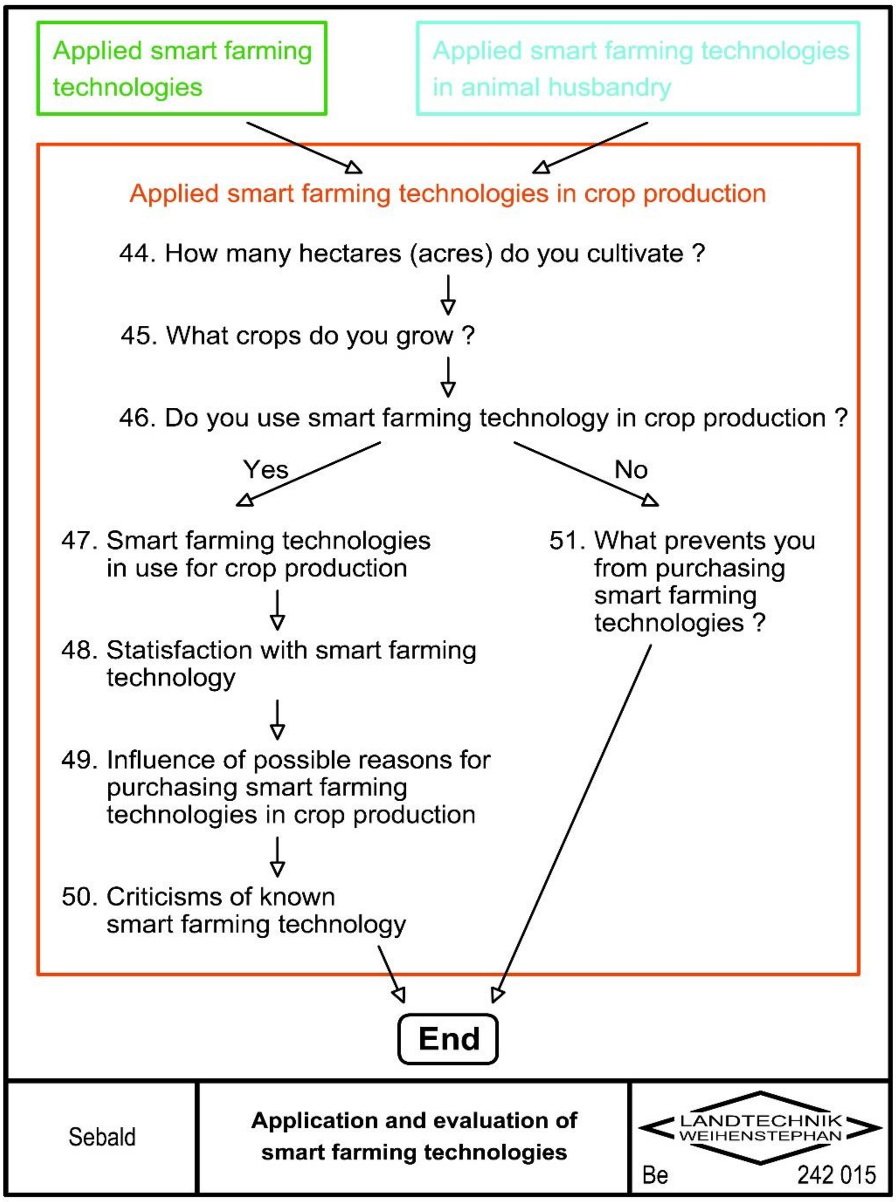


Figure 8 Detailed structure from questions 44 to the end for livestock and crop producers

The farmers could participate in the questionnaire between 03-14-2024 and 06-17-2024. To get the survey out in the field, a QR-Code and a Link for the German and English versions of the questionnaire were conducted.

Contacting the farmers USA happened especially in North Dacota (USA) through the North Dakota State University extension staff and their belonging research extension centers. Furthermore, contact persons from the University of Nebraska-Lincoln, Iowa State University, South Dakota State University, Purdue University, and Minnesota State University were contacted and helped send the survey to farmers. In addition, the North Dakota Livestock Association, other farmer associations, and the farm bureau were contacted.

In the EU, especially Germany, the questionnaire reached out to farmers from different farmers' associations, the Technical University of Munich, and alumni associations.

For the evaluation, statistical analysis software was used. Two separate Excel tables for the answers to the German and English surveys were automatically created using Microsoft® Forms® (Microsoft 365, Microsoft Corporation; Redmond, Washington, USA). Before starting, the statistical evaluation was merged, translated where necessary, and sorted. Afterward, statistical analyses were implemented using OriginPro® (Version 2024b, OriginLab®; Northampton, Massachusetts, USA).

5. Results

A total of 103 farmers answered the surveys. Thirty-nine farmers from the USA and sixty-four farmers from the EU took place. Fifty-six farmers answered the German version, and forty-seven the English Version. The average time to fill in the English survey was 07:04 minutes, and the average time to answer the German survey was 06:52 minutes.

5.1.General classification of participants and farms

In total, 62,14% of the participants were European farmers, and 37,86% were farmers from the United States. Age groups between 16-25 up to >75 answered the questionnaire. The majority of participants were between 16 and 35 (60,19%). 87,37% of participating farmers were between 16 and 55 years old. Most of the participating farmers were males (74,76%).

5.1.1. Results EU

Farmers from 11 different nations participated in the European Union, as seen in detail in Figure 9. 79,69% originated from Germany. Farmers from 6 different states took place in the survey in Germany, and most operate in Bavaria (78,57%).

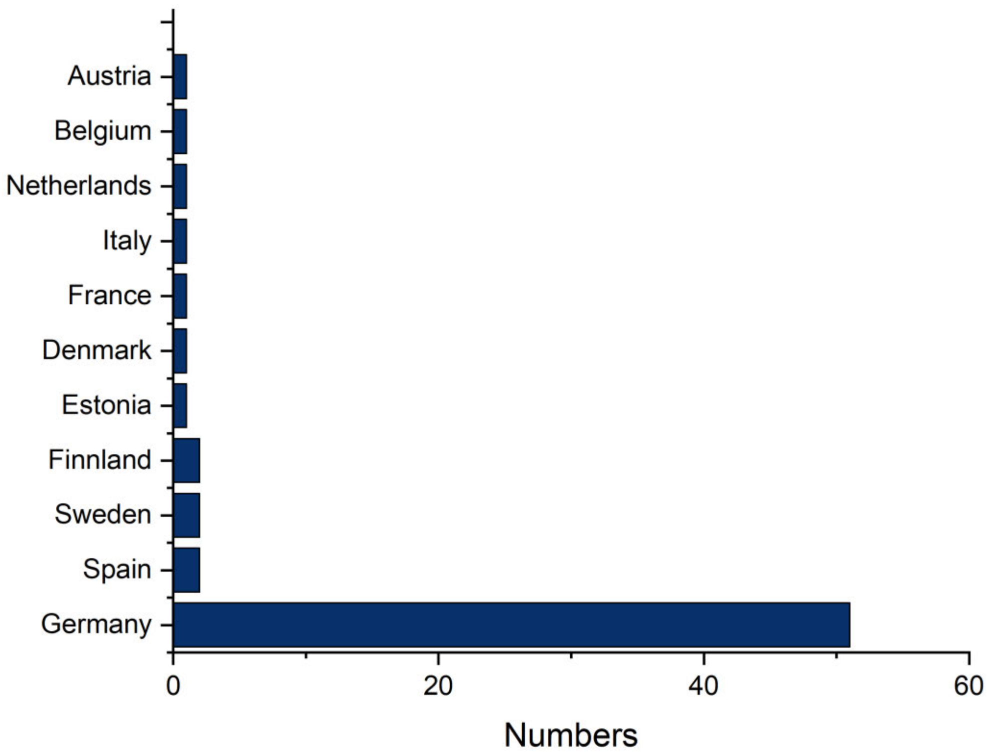


Figure 9 Participating Countries of the European Union

Age groups between 16-25 up to >75 answered the questionnaire. Most participants were between 26 and 45 (62,5%). Between 16 and 55 years of age were 85,94% of the participants. Most of the farmers who participated were males (79,69%).

In the European Union, most farms (82,81%) cultivate farmland up to 200ha (~739 acres). 51,56% (33) of the participating European Union farms focus on crop production, 40,63% (26) run mixed farms with animal husbandry and crop production, and 7,81% (5) focus only on livestock production.

As seen in Figure 10, the most grown crops are small grains. 86% of the farmers asked stated that they were growing small grains. Furthermore, Corn and Hay/Silage are cultivated by most of them. In general, a wide crop variety is seen.

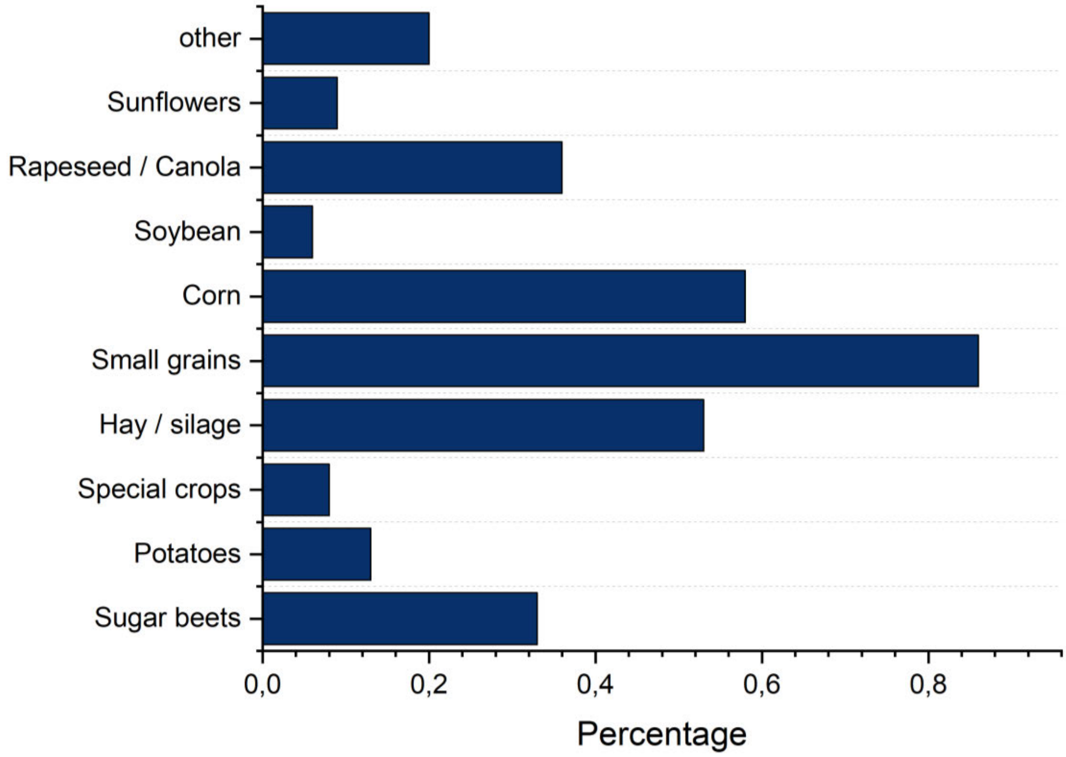


Figure 10 Crop production of participating farmers from the EU

Livestock owners from the European Union have dairy cows, cow-calf operations, growers/stockers, finishing cattle, sheep, laying hens, broiler chickens, turkeys, breeding sows, and finishing pigs. In total, 31 stated they were running a farm, including animal husbandry. With 41,9% of the livestock producers keeping dairy cows up to >1500 animals, it is the most common animal on their farms. 69,3% of the dairy cow owners have up to 120 cows on their farms. Keeping finishing pigs is the second most common livestock stated by the participating European farmers. 38,7% indicated that they had finished pigs and up to 20,000 animals. 50% keep between 500 to 2000 animals. Finishing cattle up to animals are kept by 32,2% of the livestock producers. 29% keep growers/stockers, and 29% of the livestock producers keep laying hens. The other stated animals were kept by less than 20% of the farmers.

5.1.2. Results USA

Farmers from 7 different states of the Midwest, seen in Figure 11, participated in the United States of America. 71,79% originated from North Dakota.

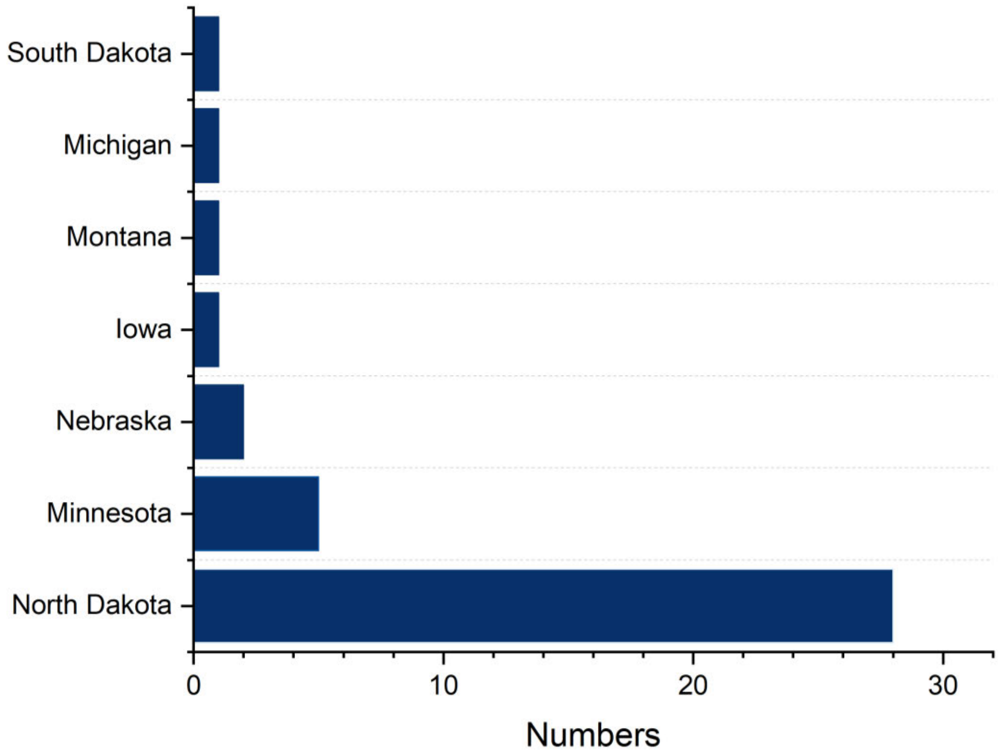


Figure 11 Participating States of the United States of America

Age groups between 16-25 up to 65-75 answered the questionnaire. Most participants were between 16 and 35 (64,1%). Between 16 and 55 years of age were 90,08% of the participants. Most of the farmers who participated were males (66,67%).

The participating farms and ranches cultivate farmland up to 5000 ha (~12 354 acres) in the USA. 46,15% (18) of the farms and ranches of the Midwest focus on crop production, 33,33% (13) run mixed farms with animal husbandry and crop production, and 20,51% (8) focus only on livestock production.

As seen in Figure 12, the most cultivated crops are corn (76,9%), soybeans (71,8%), small grains (69,2%) and hay/silage (51,3%). Most farms focus only on those crops, and the variety of cultivated crops is small.

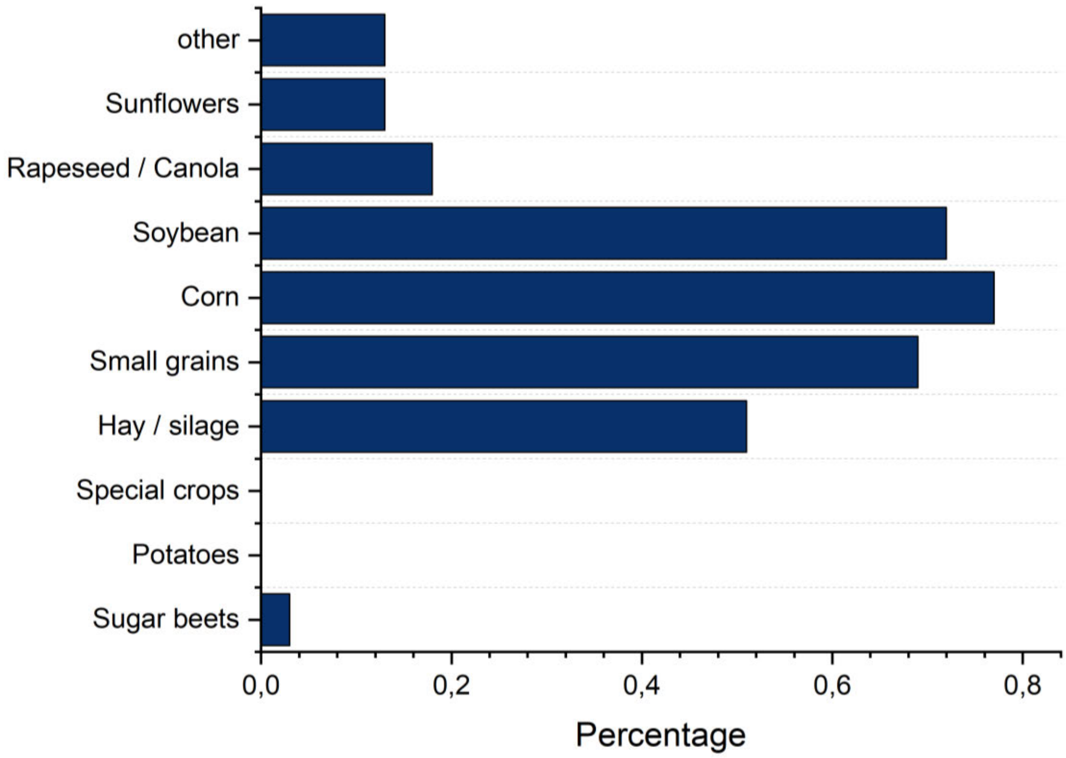


Figure 12 Crop production of participating farmers from the USA

29 farmers mentioned running a farm, including animal husbandry. The participating live-stock owners stated they had dairy cows, cow-calf operations, growers/stockers, finishing cattle, sheep, laying hens, and broiler chickens on their farm. Most livestock farmers in the United States run a cow-calf operation 57,9% keep between 100 and 300 cows. The range of kept cows was between 11 and 1000 cows. 10 out of 21 farmers stated that they should keep growers/stockers up to 2000 animals. Six farmers also keep finishing cattle, which is up to 300 animals. Laying hens of less than 100 animals are kept by 23% of the livestock producers. The other stated animals were kept by less than 20% of the farmers.

5.2. Challenges in agriculture

The section “Challenges in agriculture” is the second topic in the questionnaire and aims to determine farmers' assessment of the most discussed challenges. Every participant (N = 103) of the survey had to answer the questions number 7 and 8 of this section.

In question number 7, the farmer had to rate challenges like environmental effects, shortage of resources, climate change, public perception, agricultural policy, labor shortage, globalization, non-agricultural investors, rental/purchase prices for farmland, and income between 1, which correspond with “no challenge” and 5, which correspond with “challenge is tough to handle”.

Furthermore, question number 8 asked how the farmer rates the application of precision-/smart-/digital farming technologies for their farm. They could choose between “as an additional challenge,” “as a way to face the challenges mentioned above,” or “as a way to earn more money.”

5.2.1. Results EU

The participating European farmers assessed “Agricultural policy”, “Environmental effects”, “Climate change” and “Rental/purchase prices for farmland” as the biggest challenges for their farms. As seen in Table 4, all of these challenges have a median of 4 and a mean value more significant than 3,6, corresponding to a challenge difficult to handle for the farmers. The challenges “Public perception” and “income” have a median of 3,5 and a mean value between 3,3 and 3,5. A median of 3,5 corresponds to a challenge difficult for farmers to handle. Table 1 also shows the standard deviation and the minimum answer category (1 = “no challenge”; 2 = “challenge to handle”) that was chosen, as well as the maximum answer category (5 = “challenge is very difficult to handle”) that was selected.

Table 4 Average assessment of European farmers about challenges in agriculture

Name	Mean value	Standard deviation	Minimum	Median	Maximum
Environmental effects	4,0625	0,85217	2	4	5
Shortage of resources	3,03125	1,03845	1	3	5

Climate change	3,85938	1,08184	1	4	5
Public perception	3,45313	1,16741	1	3,5	5
Agricultural policy	4,07813	1,02825	1	4	5
Labor shortage	2,96875	1,24682	1	3	5
Globalization	3,28125	1,10509	1	3	5
Non-agricultural investors	3,29688	1,25584	1	3	5
Rental/purchase prices for farmland	3,60937	1,22949	1	4	5
Income	3,375	1,20185	1	3,5	5

A way to face the challenges mentioned in question number 7 and seen in Table 4, is precision-/smart-/digital farming technologies for 62,5% of the participants of the European Union. 15,6% consider those technologies as a way to earn more money. At the same time, 21,9% see precision-/smart-/digital farming technologies as an additional challenge. The results are shown in Figure 13.

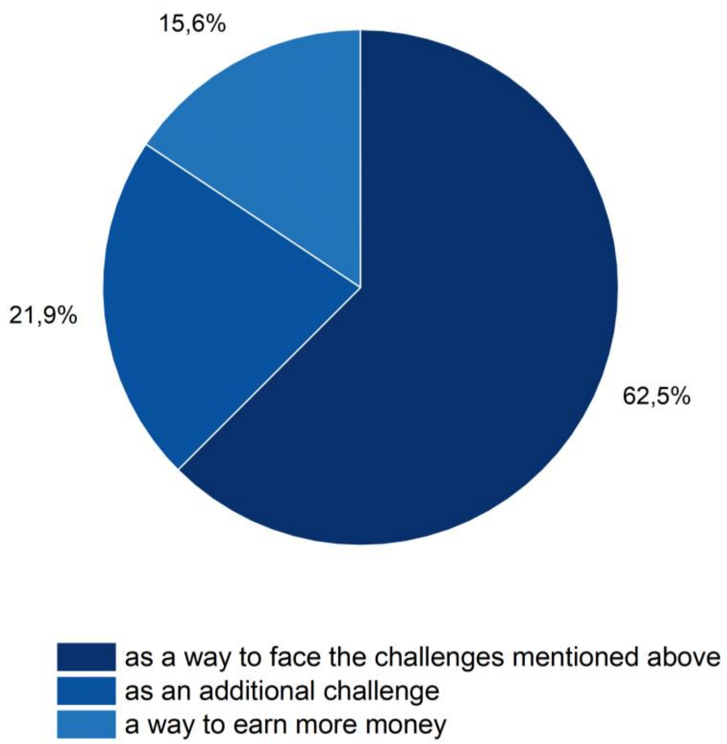


Figure 13 Answers of the European farmers to question number 8: “How do you rate the application of precision-/smart-/digital farming technologies for your farm?”

5.2.2. Results USA

American farmers rate “Rental/purchase prices for farmland” and “income” as the biggest challenges for their farms. Both challenges have a median of 4 and a mean value more significant than 3,9. All other challenges were rated with a median of 3 and mean values between 2,74 and 3,4359. The mean value, the median, the standard deviation, and the minimum answer category (1 = “no challenge”; 2 = “challenge to handle”) that was chosen, as well as the maximum answer category (4 = “corresponding to a challenge difficult to handle for the farmers “; 5 = “challenge is very difficult to handle”), is shown in detail for each common challenge for American agriculture in Table 5.

Table 5 Average assessment of American farmers about challenges in agriculture

Name	Mean value	Standard deviation	Minimum	Median	Maximum

Environmental effects	3,4359	0,85208	2	3	5
Shortage of resources	3,12821	1,23926	1	3	5
Climate change	2,74359	1,14059	1	3	5
Public perception	3,25641	1,25064	1	3	5
Agricultural policy	3,23077	0,98573	1	3	5
Labor shortage	3,41026	1,35176	1	3	5
Globalization	2,79487	0,89382	1	3	4
Non-agricultural investors	2,74359	1,29204	1	3	5
Rental/purchase prices for farmland	4,20513	0,95089	1	4	5
Income	3,92308	0,95655	2	4	5

As seen in Figure 14, 61,5% of the participating farmers in the United States see precision-/smart-/digital farming technologies as a way to face the challenges mentioned in question number 7 and seen in Table 5. 20,5% consider those technologies as a way to earn more money. In contrast, 17,9% see precision-/smart-/digital farming technologies as an additional challenge.

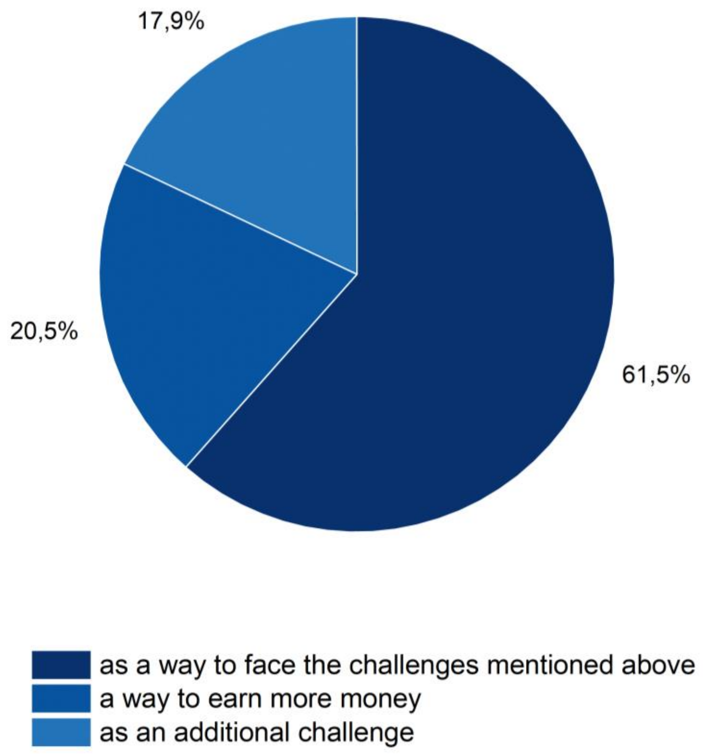


Figure 14 Answers of the American farmers to question number 8: "How do you rate the application of precision-/smart-/digital farming technologies for your farm?"

5.3. Internet connectivity in agriculture environments

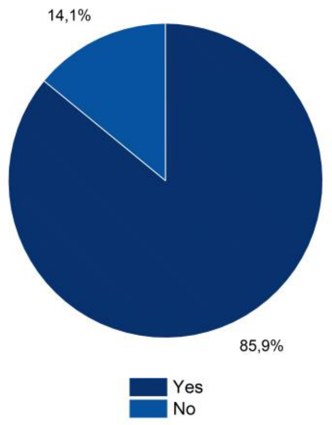
The third section, "Applied smart farming technologies," includes three questions about internet connectivity on the farm and the farmland as well as the rating of the internet speed. All participants (n = 103) had to answer these questions.

Question number 9 asked if a constant/solid internet connection is available on the farm, and question number 10 asked for internet connectivity on the farmland. The participating farmer could choose in question number 10 "yes" if there is a constant internet connection on every farmland, "no" if there is not any internet connection or cellular network available on the farmland, or "partially or depending on area" if there are some spots on the farmland with and some without internet connection.

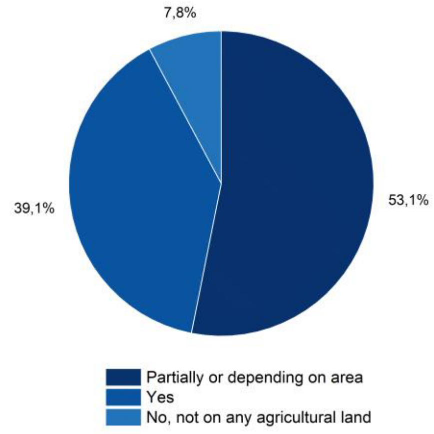
In question number 11, the farmer had to rate their subjective feeling about the internet speed. The participants could rate between 1 corresponding to a very fast Internet (e.g., watching videos without any problems or disruptions) and 5 corresponding to a very slow Internet (e.g., not possible to watch videos)).

5.3.1. Results EU

As seen in Figure 15 (A), 85,9% of the participating farmers from the EU 27 have a constant/solid internet connection on their farm. Most farmers (53,1%) do not have a constant connection to the Internet on every farmland. 7,8% don't have any solid connection on their farmland (Figure 15 (B)).



(A)



(B)

Figure 15 Internet connectivity on European farms (A) and farmland (B)

By rating the internet speed, 34,75% of the 64 participating European farmers assess it as medium by choosing "3". The second most preferred option was "2," corresponding to a good internet speed by 23,43% of the answers. This leads to a median of 3 and a mean value of 2,67, corresponding to a medium satisfaction of the internet speed on the farm and farmland. The following boxplots in Figure 16 show the distribution of the internet speed assessments in the USA and the EU by the farmers who belong there.

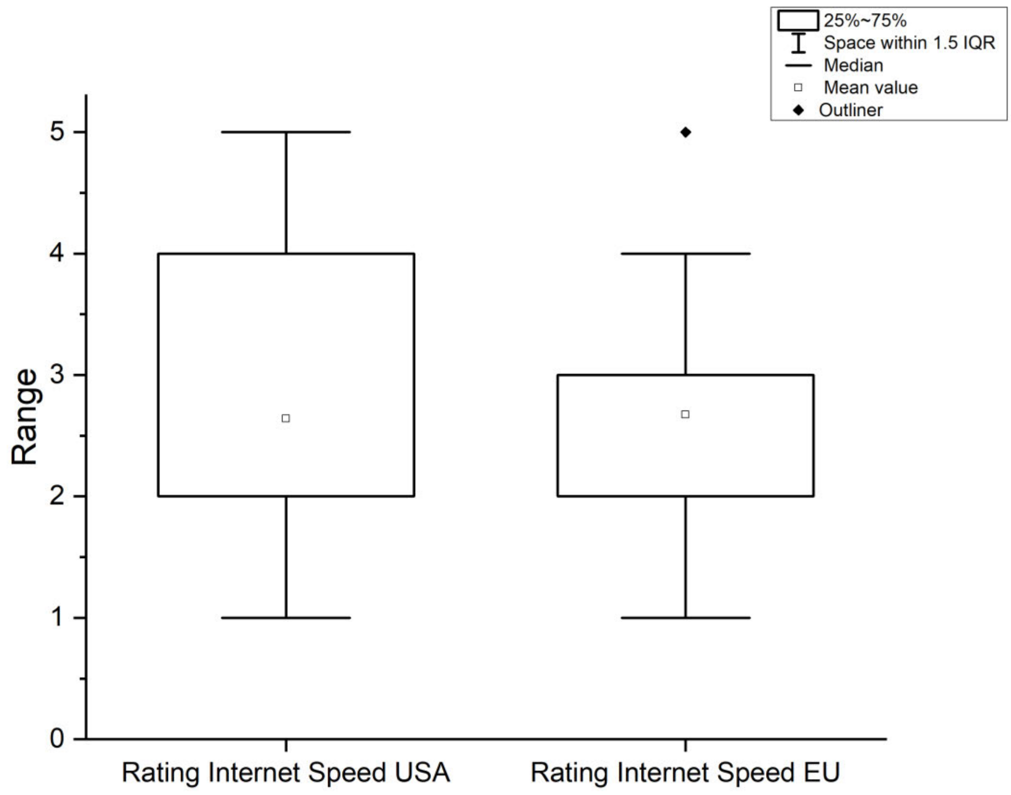


Figure 16 Rating Internet Speed on farms and farmland in the USA and the EU

5.3.2. Results USA

As mentioned above, Figure 16 also shows the distribution of the internet speed assessments by farmers from the United States. 38,46% assess the internet speed as good on their farm and farmland by choosing “2”. The second most selected option was “3”, which corresponds to the internet speed of medium quality. 20,51% of the 39 participating American farmers chose this option. This leads to a median of 2 and a mean value of 2,64, corresponding to a medium up to reasonable satisfaction with the internet speed on the farm and farmland.

A constant/solid internet connection on their farm is available for 92,3% of the participating American farmers (Figure 17 (A)). Most farmers (53,8%) do not have a constant connection to the Internet on every farmland. 17,9% don’t have any solid connection on their farmland (Figure 17 (B)).

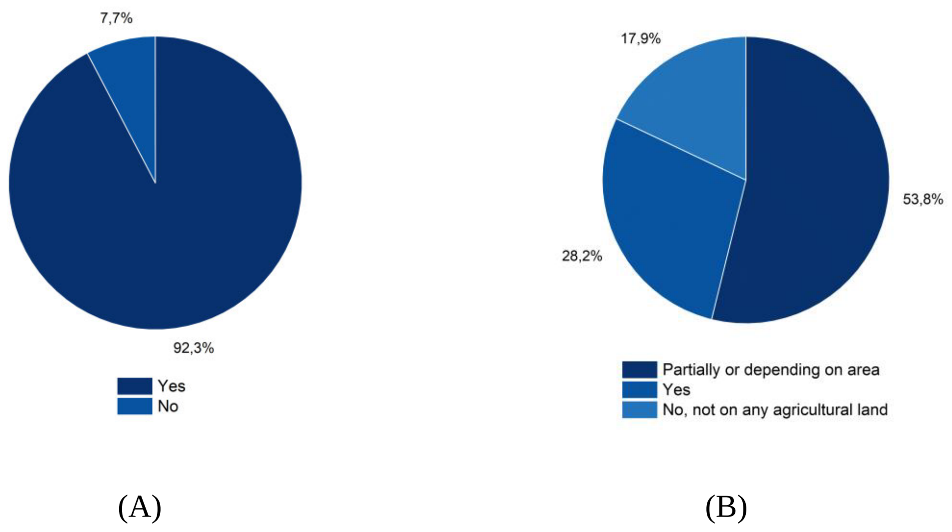


Figure 17 Internet connectivity on American farms (A) and farmland (B)

5.4.Information channels for smart farming technologies

Most participants informed themselves a minimum of monthly about smart farming technologies. 66% of all participating farmers (n = 103) informed themselves Daily, Weekly, or Monthly. The exact frequency distribution of their answers to question number 13, “How often do you actively inform yourself about smart farming technologies?” is shown in Figure 18.

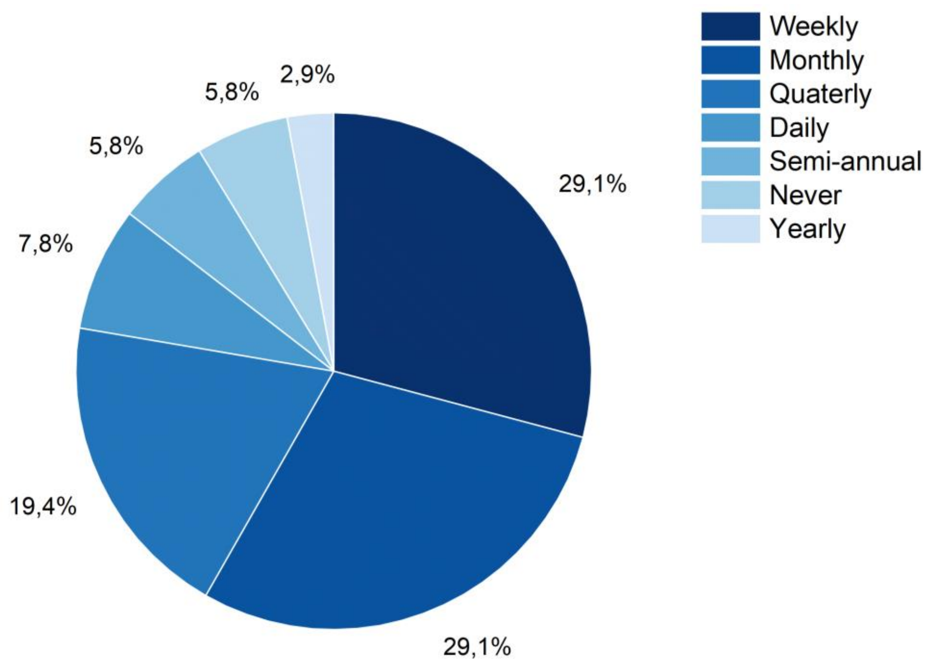


Figure 18 Information frequency of farmers' independent information searches on smart farming technologies

5.4.1. Results EU

62,5% of the participating European Farmers informed themselves a minimum of Monthly or often. The exact frequency distribution of answers of the European Farmers to question number 13, "How often do you actively inform yourself about smart farming technologies?" is shown in Figure 19.

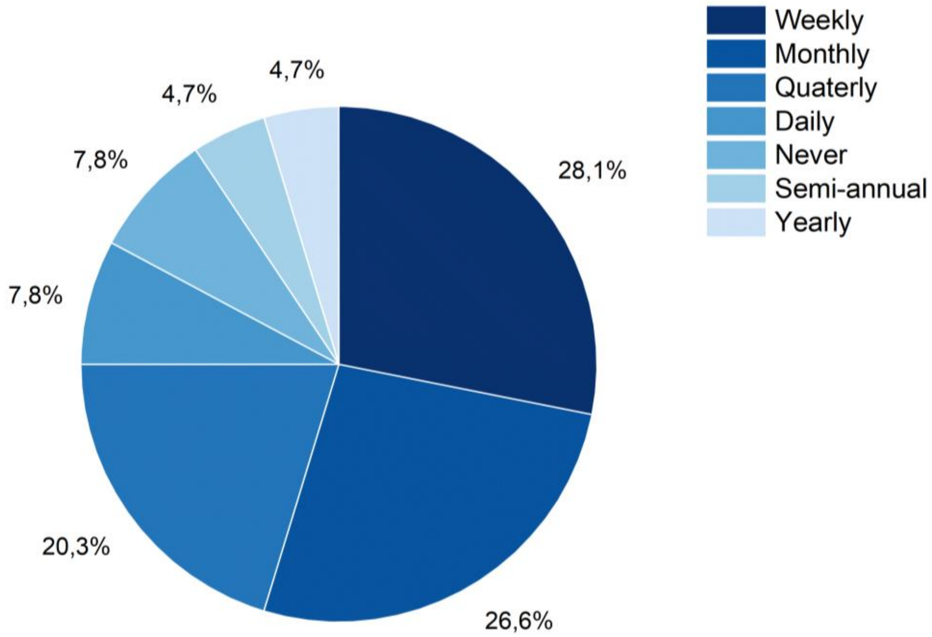


Figure 19 Information frequency of farmers' independent information searches on smart farming technologies in the EU

The farmers could select as many information sources as possible about smart farming technologies. Ten options, shown in Figure 20, were given. Farmers selected a minimum of one and a maximum of 8 different information sources for smart farming technologies. On average, each farmer uses 4 primary information sources.

75% of the participating European farmers inform themselves about smart farming technologies in "Producer magazines." 64,1% talk actively about that topic with their neighbor. 59,4% state that they inform themself actively to do their own research and have their expertise about it. Less than 25% get information about smart farming technology from "Regional and local governments", "Regional associations" or "Agricultural consultants/nutritionists". 8% of the European participants stated that they don't actively inform themselves. The number of responses for each possible source of information about smart farming technologies is shown in Figure 11.

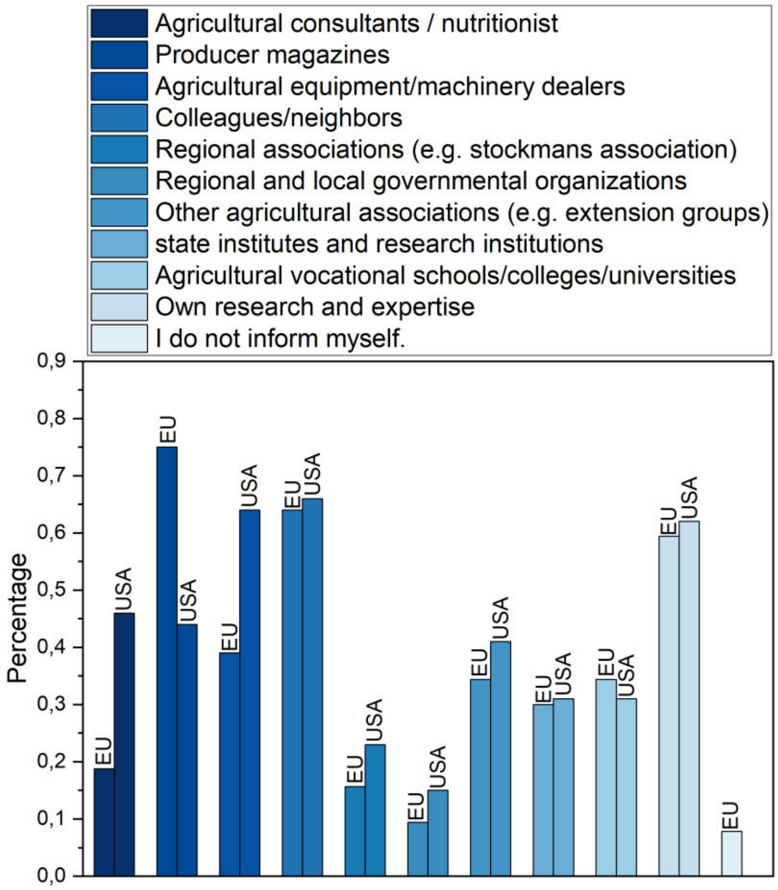


Figure 20 Proportion of used information sources about smart farming technology for farmers

5.4.2. Results USA

71,8% of the participating American Farmers (n =39) informed themselves Monthly or even more often. The exact frequency distribution of answers of the European Farmers to question number 13, “How often do you actively inform yourself about smart farming technologies?” is shown in Figure 21.

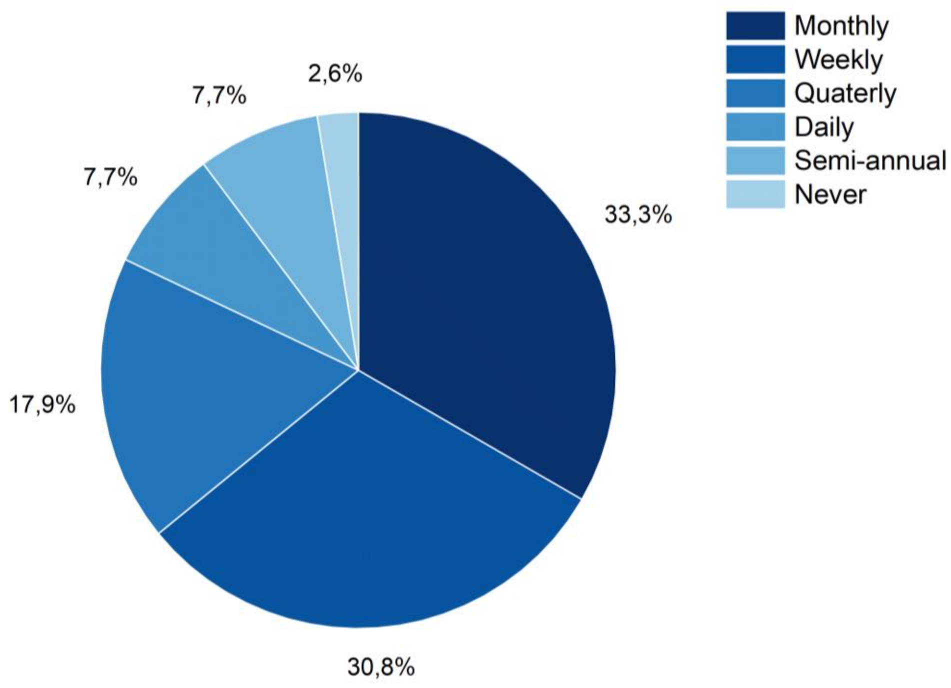


Figure 21 Information frequency of farmers' independent information searches on smart farming technologies in the USA

The farmers could select as many information sources as possible about smart farming technologies. 11 options, shown in Figure 20, were given. Farmers chose at least one and 10 different information sources for smart farming technologies. On average, each farmer uses 4 primary information sources.

67% of the 39 participating farmers from the United States get their information about smart farming technologies from their "Colleagues/neighbors", 64% from their "Agricultural equipment/machinery dealers" and 62% from their "own research and expertise". Less than 25% inform themselves through "Regional and local governmental organizations" and "Regional associations". None of the participants from the United States stated that they didn't inform themselves. Figure 20 shows the number of respondents for each possible source of information about smart farming technologies in the USA.

5.5. Applied smart farming technologies in livestock production

A total of 52 farmers run either a farm focused on animal husbandry (n = 13) or a mixed farm with crop and livestock production sectors (n = 39). 51,92% are using Smart Farming Technologies for livestock production.

5.5.1. Results EU

31 of the 64 participating European farmers run farms focusing on animal husbandry only or producing crops and livestock. 54% of those are using smart farming technologies for their livestock production. Farmers stated to use automatic milking systems, manure scraper robots, automatic bedding systems/bedding robots, automatic concentrate feeding systems, camera systems, sensors for behavioral monitoring, weight sensors, automatic lighting systems, automatic ventilation systems, automatic temperature regulation systems, Farm/Herd Management Information systems, feed delivery information systems, and forecast models. One of the stated technologies is used depending on the kind of animal husbandry minimum. It is seen that dairy cow operations are highly technologized.

Question number 40 asked about the livestock producers' satisfaction with using their well-known smart farming technologies. The farmers could choose between 1, which corresponds with very high and pleasing satisfaction, and 5, which corresponds to no satisfaction. The mean satisfaction value is 2,59, and the median is 2, corresponding to an average satisfaction. European farmers select answers from the whole answer spectrum.

Figure 22 shows box plots of satisfaction with the smart farming technologies used in the EU and the USA.

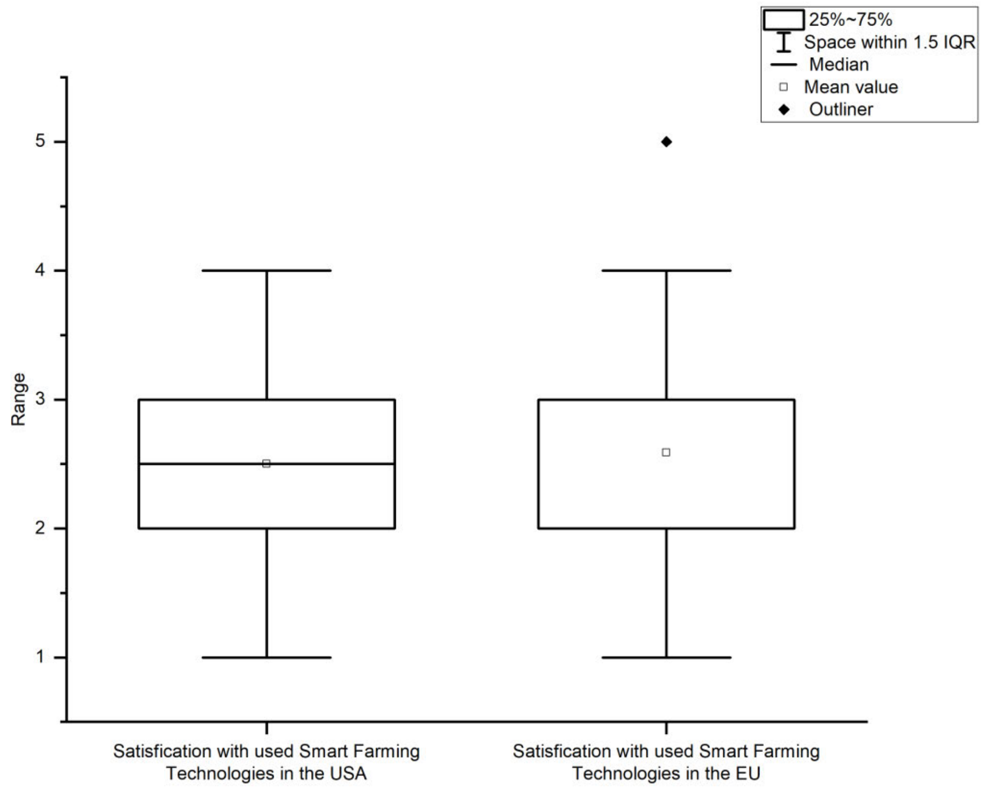


Figure 22 Satisfaction with used Smart Farming Technologies in Livestock production

Question number 41, "How would you rate the influence of the reasons given for your purchase to livestock technology?" the farmer rated if the options, shown in Table 6, had a positive, minor, or no influence on acquiring smart farming technologies for livestock:

Table 6 Influence of purchasing smart farming technologies for livestock in the EU

Options	**Positive influence**	**Minor influence**	**No influence**
Monitoring animal health	70,6%	17,6%	11,8%
Experience from colleagues	47%	41,2%	11,8%

Recommendation from an agricultural machinery dealer	23,5%	35,3%	41,2%
Government subsidies	52,9%	11,8%	35,3%
More flexible working time organization	58,8%	35,3%	5,9%
Employees/workload reduction	70,6%	11,8%	17,6%
Improving animal welfare	76,5%	17,6%	5,9%
Recommendations of your consultant	11,8%	58,8%	29,4%
Market situation	17,6%	29,4%	53%
Farm structure	41,2%	41,2%	17,6%
User-friendliness	52,9%	41,2%	5,9%

The major criticisms, seen in Figure 23, of European farmers for using smart farming technologies in livestock production are a high level of technical understanding required, insufficient user-friendliness, and unreliable functionality. 41% of the participating livestock producers of the EU don’t have critics and are very satisfied with their use of smart farming technology for animal husbandry.

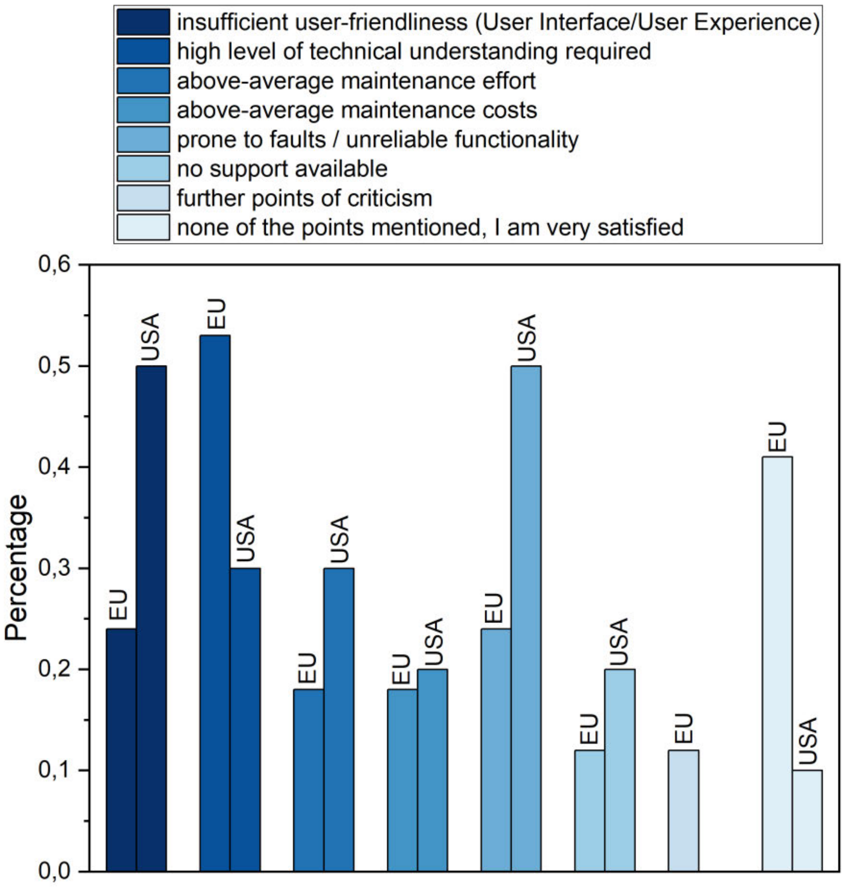


Figure 23 Stated critics of smart farming technology in animal husbandry

14 out of 31 participating European livestock producers don’t use smart farming technologies for animal husbandry on their farms. In question number 43,” What prevents you from purchasing smart farming technologies in livestock farming?“ they evaluated the reasons shown in Table 4 as strong, minor, or no influence on their decision against smart farming technology for livestock on their farms.

Table 7 Influence of not purchasing smart farming technologies for Livestock in the EU

Options	Strong influence	Minor influence	No influence
The number of animals is too low	50%	14,3%	35,7%

The number of animals is too high	0%	14,3%	85,7%
High investment costs	64,3%	28,6%	7,1%
High maintenance effort and running costs	42,9%	42,9%	14,2%
Bad experiences of colleagues	7,1%	28,6%	64,3%
Farm structure	71,5%	21,4%	7,1%
Discouraged by a consultant	0%	28,6%	71,4%
Uncertain market situation	21,4%	21,4%	57,2%
Technical expertise	35,7%	35,7%	28,6%
Insufficient user-friendliness	42,8%	28,6%	28,6%
Unreliable functionality	42,9%	35,7%	21,4%
No support available	14,2%	42,9%	42,9%

5.5.2. Results USA

21 out of 39 participating farmers from the United States run farms focused on animal husbandry or mixed production systems with crop and livestock production. 47,6% (n =10) use smart farming technologies in livestock production. 52,4% don't run smart livestock farming technologies.

7 out of 10 rangers use camera systems. Furthermore, Herd Management Information Systems, weight sensors, sensors for behavioral monitoring, forecast models, feed delivery information systems, automatic temperature regulation systems, automatic ventilation systems, automatic lighting systems, automatic basic feed delivery system/feed pusher robots, manure scraper robots, and automatic milking systems are in use on the farm of the participating American livestock producers. The highly technologized farm is the dairy farm. Nine different technologies are used there. The other farms typically use one or two smart farming technologies for livestock production.

By rating satisfaction with the known smart farming technologies, the mean satisfaction value and the median are 2,5, corresponding to an average and neutral satisfaction. The American farmers select every opportunity for an answer except option 5, which corresponds to no satisfaction. Figure 22 shows the related box plot of the satisfaction of smart livestock technologies of the participating farmers from the EU and USA.

As well as the European farmers, the 10 participants from the United States who are using smart livestock technologies rated the options for purchasing those technologies if they had a positive, minor, or no influence. The results are shown in Table 8.

Table 8 Influence of purchasing smart farming technologies for livestock in the USA

Options	**Positive influence**	**Minor influence**	**No influence**
Monitoring animal health	70%	10%	20%
Experience from colleagues	30%	50%	20%
Recommendation from an agricultural machinery dealer	30%	30%	40%
Government subsidies	0%	30%	70%

More flexible working time organization	30%	50%	20%
Employees/workload reduction	40%	20%	40%
Improving animal welfare	90%	10%	0%
Recommendations of your consultant	20%	60%	20%
Market situation	20%	60%	20%
Farm structure	40%	40%	20%
User-friendliness	60%	40%	0%

As seen in Figure 23, the major criticisms of the known smart farming technologies for livestock are insufficient user-friendliness, high technical understanding required, unreliable functionality, and above-average maintenance effort.

11 out of 21 participating farmers from the United States were led to question number 43 instead of questions 38 to 42 (see Chapter 2 Material and Methods). How they rated the influence of the given options against purchasing smart farming technologies is shown in Table 9.

Table 9 Influence for not purchasing smart farming technologies for livestock in the USA

Options	**Strong influence**	**Minor influence**	**No influence**

The number of animals is too low	36,4%	27,2%	36,4%
The number of animals is too high	0%	27,3%	72,7%
High investment costs	90,9%	9,1%	0%
High maintenance effort and running costs	42,9%	42,9%	14,2%
Bad experiences of colleagues	18,2%	27,3%	54,5%
Farm structure	18,2%	72,7%	9,1%
Discouraged by a consultant	0%	9,1%	90,9%
Uncertain market situation	45,4%	36,4%	18,2%
Technical expertise	36,4%	36,4%	27,2%
Insufficient user-friendliness	36,4%	45,2%	18,2%
Unreliable functionality	36,4%	45,4%	18,2%
No support available	27,3%	54,5%	18,2%

5.6. Applied smart farming technologies in crop production

Ninety farmers run either a crop production (n = 51) or a farm with livestock and crop production (n = 39). The 13 farmers who indicated running a farm focused on animal husbandry were also asked about "Applied smart farming technologies in crop production". 63,1% of the 103 participants use smart farming technology in crop production. In the following paragraphs, the results of the farmers of the European Union and the United States are considered separately.

5.6.1. Results EU

56,25% of the European participants use smart farming technology for crop production.

Figure 24 shows the smart farming technologies applied in crop production and the amount of use in the EU 27. The most used technologies, with an amount larger than 50%, are digital field mapping systems, autonomous steering systems, and maps derived from satellite data.

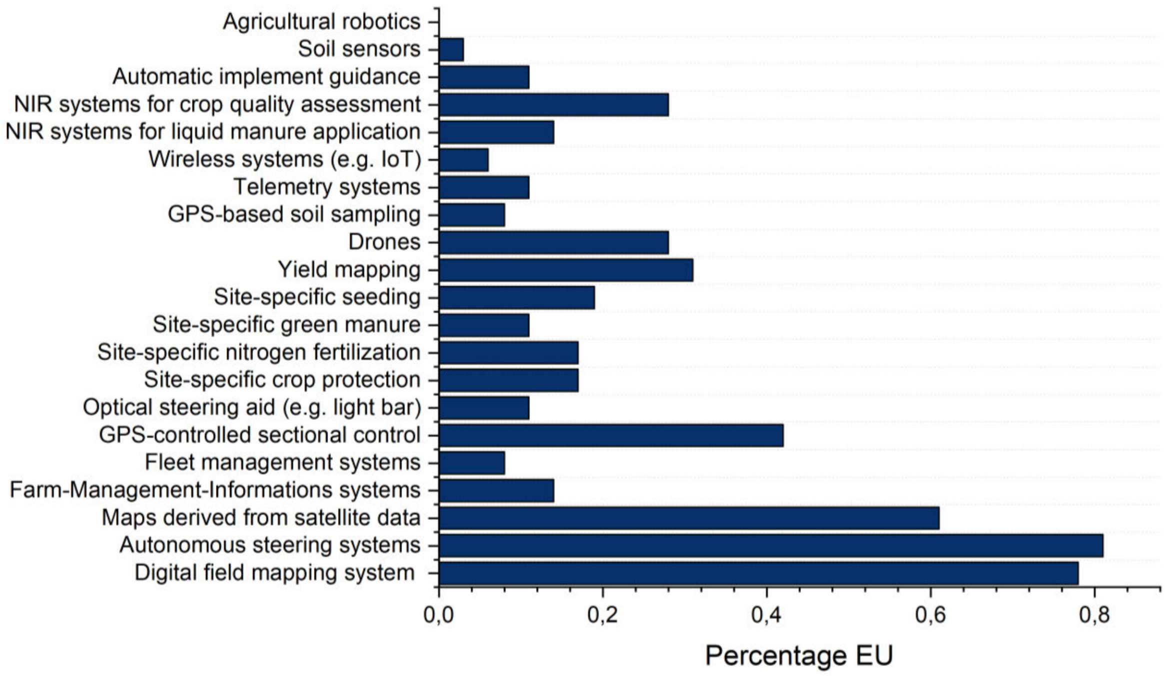


Figure 24 Applied smart farming technology of the European participants in crop production.

The satisfaction with the use of smart farming technology in crop production was asked in question number 48. Thirty-six farmers could rate, like in question number 40, their satisfaction between 1, corresponding to being very satisfied with the used smart farming technology, and 5, corresponding to dissatisfaction and no satisfaction. The farmers selected all possible answer options. 75% rated satisfaction with the known smart farming technologies as good or very good. The mean satisfaction value is 2,03, and the Median was 2, corresponding to reasonable satisfaction with the known smart farming technology. The associated boxplot is seen in Figure 25, where the boxplot belonging to the responses from the USA is also shown.

Figure 25 Satisfaction with used Smart Farming Technologies in crop production

In question number 49, the farmers had to evaluate the positive, minor or no influence of given possible reasons for acquiring smart farming technologies for crop production. Table 10 shows the options asked and the influence rating.

Table 10 Influence of purchasing smart farming technologies for Crop Production in the EU

Options	Positive influence	Minor influence	No influence
Potential yield increase	33,3%	55,6%	11,1%
Experience from colleagues	41,7%	50%	8,3%
Recommendation from an agricultural machinery dealer	27,8%	30,5%	41,7%
Government subsidies	30,5%	16,7%	52,8%
More flexible working time organization	52,8%	27,8%	19,4%
Employees/workload reduction	83,3%	11,1%	5,6%
Potential resource savings	63,9%	33,3%	2,8%
Recommendations of your consultant	19,4%	30,6%	50%
Market situation	13,9%	41,7%	44,4%
Farm structure	38,9%	44,4%	16,7%
User-friendliness	58,33%	33,33%	8,33%

31% of the European farmers who use smart farming technology are satisfied with their known technology and don't mention any criticism. Most farmers stated that a high technical understanding and insufficient user-friendliness for the known smart farming technologies are critical to assess. In particular, the criticism of EU and USA farmers is seen in Figure 26.

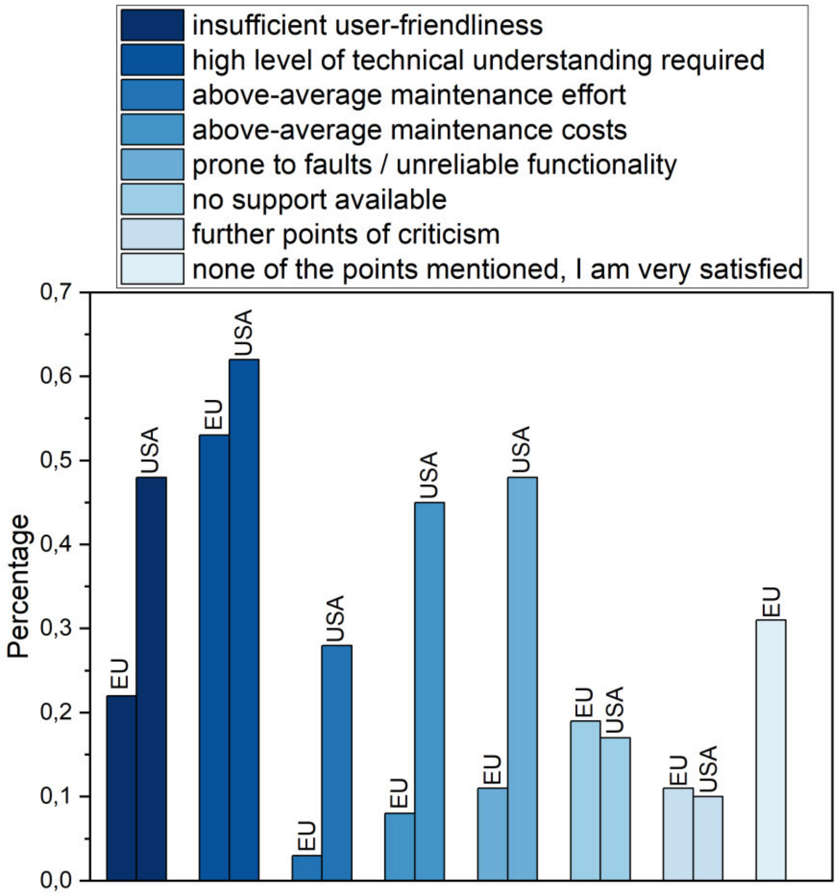


Figure 26 Stated critics of smart farming technology in crop production

The 28 European farmers who stated not using smart farming technology were asked question number 51 instead of questions 47 to 50. Question number 51 asked about the influence of not getting smart farming technologies for crop production yet. The results are shown in Table 11.

Table 11 Influence of not purchasing smart farming technologies for Crop Production in the EU

Options	**Strong influence**	**Minor influence**	**No influence**
Operation too small	60,7%	28,6%	10,7%
High investment costs	85,7%	14,3%	0%
High maintenance effort and running costs	46,4%	0%	53,6%
Bad experiences of colleagues	0%	28,6%	71,4%
Farm structure	42,8%	28,6%	28,6%
Discouraged by a consultant	0%	21,4%	78,6%
Uncertain market situation	14,3%	35,7%	50%
Technical expertise	21,4%	42,9%	35,7%
Insufficient user-friendliness	36%	32%	32%
Unreliable functionality	21,4%	35,7%	42,9%
No support available	14,3%	28,6%	57,1%

5.6.2. Results USA

29 out of 39 participating farmers from the USA are using smart farming technologies.

Digital field mapping systems, autonomous steering systems, maps derived from satellite data, GPS-controlled sectional control, and yield mapping are the most used smart farming technologies, with a percentage proportion over 50%. This is seen in Figure 27.

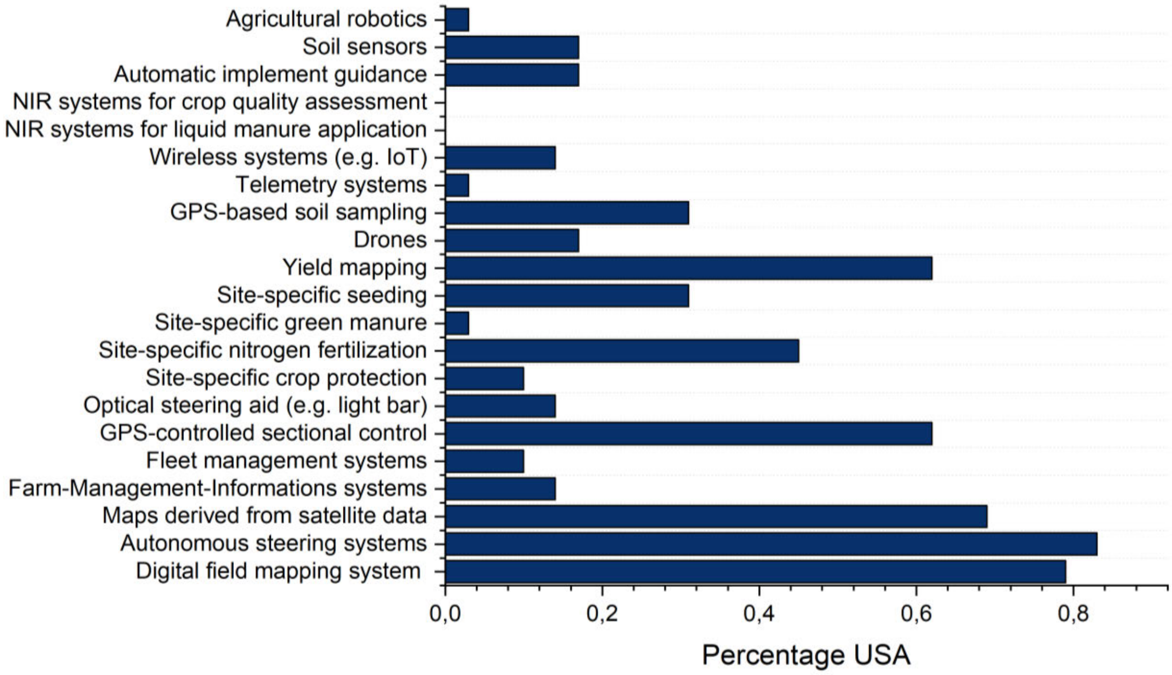


Figure 27 Applied smart farming technology of the American participants in crop production.

The boxplot of satisfaction with the smart farming technologies used by those 29 farmers is shown in Figure 26. They chose answer options between 1, which corresponded to being very satisfied with the smart farming technology used, and 4, which corresponded to low satisfaction. 62,1% stated an excellent or outstanding satisfaction with the known smart farming technologies. The mean satisfaction value is 2,28, and the median is 2, corresponding to reasonable satisfaction with the known smart farming technology.

Table 12 shows the answers of the 29 farmers from the United States who evaluated different reasons for purchasing smart farming technologies. Those are the results of question number 49 for the United States.

Table 12 Influence of purchasing smart farming technologies for Crop Production in the USA

Options	Positive influence	Minor influence	No influence
Potential yield increase	89,7%	10,3%	0%
Experience from colleagues	55,2%	34,5%	10,3%
Recommendation from an agricultural machinery dealer	58,6%	31%	10,4%
Government subsidies	24,1%	41,4%	34,5%
More flexible working time organization	65,5%	20,7%	13,8%
Employees/workload reduction	58,6%	31%	10,4%
Potential resource savings	69%	31%	0%
Recommendations of your consultant	31%	58,6%	10,4%
Market situation	31%	58,6%	10,4%
Farm structure	44,8%	51,7%	3,5%
User-friendliness	51,7%	41,4%	6,9%

All farmers stated a minimum of one criticism of the smart farming technology. The most criticized points are a high level of technical understanding, insufficient user-friendliness, above-average maintenance effort, above-average maintenance costs, and unreliable functionality. The exact stated critics and their proportions of the answers of farmers of the EU and USA are seen in Figure 26.

The 10 American farmers who stated not using smart farming technology were asked question number 51 instead of questions 47 to 50. The ratings of the options against purchasing smart farming technology for crop farming are shown in Table 10.

Table 13 Influence of not purchasing smart farming technologies for Crop Production in the USA

Options	**Strong influence**	**Minor influence**	**No influence**
Operation too small	60%	30%	10%
High investment costs	90%	0%	10%
High maintenance effort and running costs	80%	0%	20%
Bad experiences of colleagues	20%	20%	60%
Farm structure	50%	20%	30%
Discouraged by a consultant	10%	0%	90%
Uncertain market situation	10%	40%	50%
Technical expertise	30%	40%	30%

Insufficient user-friend-liness	30%	30%	40%
Unreliable functionality	20%	50%	30%
No support available	10%	40%	50%

6. Discussion

The following chapter focuses, on the one hand, critically on the applied Methodology of an online survey, rates it, and contextualizes it in conjunction with social sciences in agriculture. On the other hand, the chapter compares the questionnaire results with similar survey results of government institutions of the EU and the USA. Furthermore, the results of both areas will be compared and categorized.

6.1. Discussion Methodology

Comparing the number of participants in the survey with surveys of national governments, governmental institutions, and other researchers, the number of participating farmers for “Application and Evaluation of Smart Farming Technologies” with a total of 103 is low. Most official surveys had more participants (LOWENBERG-DEBOER UND ERICKSON 2019). Regarding the number of participants from the EU (N = 64) and the USA (N = 39), more European farmers took place in the survey. One possible reason for this could be the location and name recognition of the executing organization (Technical University of Munich, Chair for Agriculture Systems Engineering), which is more well-known in the EU27 than in the United States. Another reason could be the period in which the survey took place. It is shown that farmers respond more often to surveys during the winter period until March because after this, the busy work period with field cultivation starts, and their workspace changes from the office to the outdoors. This survey took place from 03-14-2024 to 06-17-2024, corresponding with the busy times for planting, fertilizing, and plant protection treatments in both areas. Furthermore, in the USA, the calving time started on the ranges with cow-calf operations. Also, by talking about responses to surveys in general, with researchers and farmers in the USA and the EU, the researchers mainly stated that they have difficulty getting responses. Farmers said they get too many surveys from different organizations, so they are not interested in answering them. Also, they don’t want to publish too much information about their business. To motivate farmers to participate in surveys, the surveys sometimes include a lottery or a monetary motivation, are part of an official agricultural census, or are from a governmental side (PENN UND HU 2023; BROSNAN ET AL. 2021). For example, Gandorfer and Gabriel did it as part of the official multiple requests for Bavaria subsidies (GABRIEL UND GANDORFER 2022).

One similar survey regarding the method and the aim was conducted by Fountas 2002. It aimed to compare Denmark's agriculture with the corn belt of the United States. Fountas et al. sent farmers a survey about precision agriculture via mail and got 136 responses and a response rate of over 20%. In the survey “Application and evaluation of smart farming technologies,” there is no proof of how many farmers reached the online link because Extension staff, association members, university staff, students, and alumni association members were contacted, and they sent it further. It is assumed that over 1000 farmers in the USA were contacted and around 500 to 1000 in the European Union. Regarding the assumption, the response rate is under 5%, categorized as low, with comparable surveys (FOUNTAS ET AL. 2005). Therefore, low survey participation is a well-known challenge for social studies (BROSNAN ET AL. 2021).

Although several regional survey data about adopting smart farming technologies are available, not two, even if they look the same, are precisely the same. Most surveys differ by the type of target population and the way it was sampled, the topic of interest, the sponsor and agency respectively funding and executing the study, the mode through which the survey was administrated, the frequency of the responses, the geographical scale and scope of the study and the reason why and for which institution and with which goal the data has been collected (STOOP UND HARRISON 2012). This survey had two versions, one in English and one in German. The German one only responded in the EU, while the English one mainly got answered in the United States. Both surveys were spread slightly differently because the existing network and range of people in the United States were predominantly restricted to Universities and Extension centers and some personally known farmers and rangers. In the EU, the survey was primarily spread the same way. Still, a network of farming organizations existed, and it was possible to reach more farmers who may not have direct contact with Universities or an Academic background. The question about an academic background wasn’t included in the survey. Still, how it was spread, the main responding age group, and the positive feedback on using smart farming technologies led to the assumption that most participants were or are at universities. In this case, it won’t reflect the actual educational standard of average farmers in both areas, but it leads to the assumption of a high human capability (M.-L. AUGERE-GRANIER; DELAY ET AL.). But there is no actual proof for this assumption. Furthermore, farmers are generally a very heterogeneous target population because of different farm structures, frameworks, farm focuses, crops, soil, climate, management philosophies, and more factors. Even in a small area, the geographical conditions are various. This mass of factors influencing the agricultural sector makes surveys challenging to compare. As mentioned, much data is available from different surveys and literature about precision agriculture. Smart farming, digital agriculture, and ‘Agriculture 4.0’. This type of research could be classified as social sciences in agriculture. Furthermore, the subtitles and main objectives of those research studies and surveys are difficult to cluster. Klerkx et al. clustered the most known surveys into five topics. Those topics Klerkx named are 1) the uses and adaptation of digital technologies on farms; 2) the effects of digitalization on farmer identity, farmer skills, and farm work; 3) the power, ownership, privacy, and ethics in digitalizing agricultural production systems and value chains; 4) digitalization and agricultural knowledge and innovation systems (AKIS); and 5) economics and management of digitalized agricultural production systems and value chains. Four further thematic for new research topics were also mentioned by Klerkx et al. Those new potential fields for social sciences in agriculture are 1) Digital agriculture socio-cyber-physical-ecological systems conceptualizations, 2) Digital agriculture policy processes, 3) Digitally enabled agricultural transition pathways, and 4) Global geography of digital agriculture development. (KLERKX ET AL. 2019). The conducted survey could be categorized as part of the “Global geography of digital agriculture development” because of the structure, category of questions, and the comparison of the EU and the USA.

6.2. Discussion Results

Despite the small number of participants already discussed, the participating farms reflect both regions' common farm types and operation systems.

As mentioned in Chapter Two, the most growing crops in the EU27 are wheat, corn, and barley. Participating farmers mostly grow small grains, including wheat, barley, and corn. The third central arable culture is hay/silage, which is also conclusive regarding livestock production. Europe is leading in producing dairy products and the top 5 in beef production. Bovine's leading food source is grass, hay, or silage. The broad variety of different crops is also typical for European farms. The comparable high share of farms growing sugar beets in the EU 27 reflects the region where most responses came from. Germany and France are the leading producers of sugar beet in the EU27. The European Union is the world-leading producer of sugar beet (EDWARD COOK). The stated farm sizes of the participants' operations also reflect the agricultural structure of the EU. 62,4% cultivate less than 100 ha. The average farm size in the EU 27 is less than 20 ha and is mainly classified as family businesses.

Nevertheless, the result reflects European agriculture in connection with smart farming goods because farm size plays a significant role in adopting smart farming technologies. Also, the age of the participants, which was mostly > 40, isn’t average. Still, it shows that mostly young farmers adopt smart farming technology and are interested in it, as Schimmelpfenning and Lowenberg mentioned (SCHIMMELPFENNIG UND LOWENBERG-DEBOER 2021).

The small number of participating farmers and rangers from the USA, especially Midwest States like North Dakota, reflects the typical farms for this region. Most growing crops are corn and soybean, concentrating on all states of the Midwest. Further, small grains like wheat are also significantly grown in arable cultures in the United States, focusing on the middle of the United States, like Kansas and the North of it, for example, North Dakota. Most participating farmers were from North Dakota, and their answers reflected this allocation of crops. In addition, the production of hay/silage seems to be very common, which is logical regarding livestock production. Beef cattle and cow-calf-operation systems are those regions' major livestock production systems. The average farm size, for example, is around 600 hectares in North Dakota. 63,8% of the participants stated to cultivate 400 hectares and more. This reflects the different dimensions of farms in the United States compared to the EU. Also, the primary age group of the participants is > 40. This leads to the conclusion that young farmers are more interested in smart farming technology.

Another indicator for the statement that the adoption of smart farming technology is in context with farm size and age of the farmer is confirmed by the fact that the majority of participants in the EU (78,1%) and the USA (79,4%) categorize smart farming technologies as a way to face challenges for agriculture or as a way to earn more money. Only about 20% in both areas see smart farming technologies as an additional challenge. In the EU, environmental effects, climate change, agricultural policy, and rental/purchase prices for farmland were stated as very difficult to handle, corresponding to a mean value of > 3,5 seen in Table 4. The participating farmers of the United States indicated that rental/purchase prices for farmland and income are the challenges most difficult to handle, with a mean value >3,5 seen in Table 5. The European farmers generally rated all named challenges (n = 10) except shortage of resources, labor shortage, rental/purchase prices for farmland, and income less positive regarding the mean value than farmers from the United States. The challenges in the context of environmental effects and climate change are especially significant for European farmers. One reason for that different perspective was probably the difference in agricultural policy strategies between the USA and the EU. In Europe, direct payments and subsidies from the government are becoming more related to environmentally friendly farming practices in de CAP 2023-27. Also, discussions about the European Green Deal, biodiversity strategy, and Farm to Fork strategy affect farmers' practices. Most of those topics were discussed in the public media and led to broad popularity, although the GDP impact of the agricultural sector is just 1,4%. In the USA, the effect of agriculture on the environment is also well known. The proportion of the US national greenhouse gas emissions is 8%, with a GDP of 0,7% (LEHNER UND ROSENBERG 2018; USDA ECONOMIC RESEARCH SERVICE 2024b). The investment in sustainable, friendly agriculture projects depends on the government. During the Trump era, 2019, the budget for agriculture research was cut. Nevertheless, experts stated that the research budget needed to be increased from 2 billion dollars to over 5 billion to promote environmentally friendly agriculture (LEHNER UND ROSENBERG 2018). The farmers in the USA are primarily self-responsible, with less financial support and fewer regulations than European farmers. Therefore, income and costs seem to play a more prominent role and are more challenging than for EU farmers.

However, in the EU and the USA, farmers see smart farming technologies as a way to face challenges or become more profitable than a further challenge.

In livestock production, 54% of the European participants focusing on livestock farming stated that they were using at least one smart livestock farming technology. In the United States, 47,6% of the participating livestock producers used at least one smart livestock farming technology. Regarding crop production, 56,25 % of the European participants and 74,35% of the American participants use a minimum of one smart farming technology compared to other surveys and governmental statements from different countries like Loewenberg-DeBoer and Erickson did. This survey's adoption share is closely twice that of surveys with more participants and official studies (LOWENBERG-DEBOER UND ERICKSON 2019). This led to the assumption that most people interested in smart farming technologies participated in this survey, and the actual adoption rate was much lower.

Another reason for this assumption is that over 60% of participating farmers in both regions stated informing themself about smart farming technologies minimum monthly. Around 60% in both areas said they research and gain expertise in smart farming technology. This also reflects the assumption that this survey's participants were mainly interested in smart farming technology and highly educated.

Besides their own research and expertise, the major information channels for European farmers who want to learn more about smart farming technologies are producer magazines and other farmers. In the United States, farmers mainly use their machinery/equipment dealer and their colleagues as primary information sources besides their expertise. Another noticeable aspect of using information sources, besides that European farmers use producer magazines more often and American farmers use their dealers more often, is that in the United States, almost 45% of farmers talk with their agricultural consultants/nutritionists about smart farming technologies. In the EU, not even 20% said they get information about it from their consultant. Possible reasons are the different farm structures, which are more large-scale in the USA and scaled in the EU, and the more business-orientated promoted farming in the United States (UNITED STATES CONGRESS 2024).

Reasons with predominantly positive influence for purchasing smart farming technologies in crop production for farmers from the USA were a potential yield increase, the experience from colleagues, the recommendation from an agricultural machinery dealer, more flexible working time organization, employees/workload reduction, potential resource savings and a sufficient user-friendliness of the technology. Those results reflect the stated information sources and their influence on the one hand and the more business-focused agricultural practice in the USA on the other hand. In the EU, most farmers stated that more flexible working time organization, employee/workload reduction, potential resource savings, and sufficient user-friendliness of the technology positively influence purchasing the technology. In the EU, the workload reduction has the most significant impact, and in the United States, the potential yield increases. This reflected the already stated different understanding of agriculture as a business, while in Europe, most farms are small-scaled and family businesses with only family workers, while in the United States, the majority of farms are also family businesses, but especially in the Midwest, the mid-size and large-scale family farms share is high. Also, the US and the EU define a small-scale farm differently. In the USA, small-scaled farms are farms with a gross cash farm income of less than 350.000 dollars, while in Europe, mainly the cultivated farmland and the amount of family workers are defined in small- and large-scale farms. For example, in Germany, the average gross cash farm income in Germany, one of Europe's major agriculture goods producers was 2022/23 113.900 € (BUNDESMINISTERIUM FÜR ERNÄHRUNG UND LANDWIRTSCHAFT (BMEL) 2024). Although the Euro and Dollar are different units, the difference is so big that this doesn’t matter. This highlights the difference in farm structure and understanding of farming in both regions.

The most common smart farming technologies for crop production are digital field mapping systems, autonomous steering systems, and maps derived from satellite data in both regions. Further, the majority of the participants from the USA use smart farming technologies, GPS-controlled section control, and yield mapping. This also reflects farmers' priorities, which were mentioned before. Near-infrared systems, whether used for liquid manure application or crop quality assessment, are only used by the participating European farmers, which could be an effect of the stricter regulations for manure application in the EU (EUROPEAN COMMISSION UND AGRICULTURE AND RURAL DEVELOPMENT 2024a). Farmers in the EU and the USA generally rated their known smart farming technology for crop production as good. Nevertheless, US farmers seem a little more critical than European farmers. When asked about the major critics of their known and used smart farming technology, almost one-third of the European farmers stated that they were delighted without any criticisms. In contrast, none of the American farmers who asked this question chose this answer. The main criticism, with around 50% of the European participants, is the required high-level technical understanding of smart farming technologies. Further, insufficient user-friendliness and no available support were mentioned by around 20%. The necessary high level of technical experience is the main criticism in the United States. Almost 50% criticized the insufficient user-friendliness. This leads to the conclusion that on the one hand, education, and training for smart farming technologies suffer as well, as on the developers' side, an intuitive user experience is needed. This has also been detected in publications by Loewenberg, Gandorfer, Gabriel, and other researchers mentioned before and effects on the adaption of those technologies (GIUA ET AL. 2022; GABRIEL UND GANDORFER 2022; PFEIFFER ET AL. 2021; GABRIEL ET AL. 2021; FOUNTAS ET AL. 2005; LOWENBERG-DEBOER 1998; LOWENBERG-DEBOER ET AL. 2022).

Almost 50% of farmers from the United States also mentioned the above-average maintenance costs and unreliable functionality as two major criticisms; this seems not to play a strong role for the participating European farmers who use smart farming technologies. Also, those farmers from the United States who don’t use any smart farming technology for crop production stated the most influential reasons against it are high maintenance efforts and running costs and high investment costs for their decision. Furthermore, 60% mentioned that their operation is too small to use smart farming technologies. In the European Union, the non-adaptors also mentioned small operations and high investment costs, too. These statements confirm the relationship between farm size and technology adaption, as stated by

Lowenberg-DeBoer and Schimmelpfennig (SCHIMMELPFENNIG UND LOWENBERG-DEBOER 2021).

Although the number of participants for the livestock chapters of the questionnaire is low, the reasons for using smart livestock technology in both regions are mostly the same. Monitoring animal health and improving animal welfare are the most significant reasons for purchasing smart livestock farming technologies. The most used technologies in livestock are camera systems, sensors for animal monitoring, and herd-management systems. Those technologies reflect why farmers purchase smart farming technology for livestock production. Furthermore, sufficient user-friendliness influences the purchase of smart farming technology in animal husbandry. Furthermore, more flexible working hours and reduced workloads and employees strongly influence European livestock farms, as well as government subsidies. Compared to the United States, more subsidy programs exist to support smart livestock farming technologies to improve animal welfare and reduce environmental impacts, so governmental subsidies could be the reason for purchasing this new technology (EUROPEAN COMMISSION UND AGRICULTURE AND RURAL DEVELOPMENT 2024a). Comparing satisfaction with smart farming technology for livestock production of both regions, it is rated as good, with a median of 2 in the European Union and 2,5 in the USA, corresponding to good to normal satisfaction. Almost 45% of participating European livestock farmers who use smart farming technology for livestock mentioned being very satisfied without any criticism for the used technology. The significant criticisms for smart livestock farming technology are comparable to crop production mentioned before. A required high level of technical understanding, insufficient user-friendliness, and unreliable functionality were stated the most in both regions. Nearly one-third of the USA participants mentioned an above-average maintenance effort. This underlines the assumption mentioned by the criticism for crop production that more training and education for the farmers and a customer-centric development focused on intuitive usability is needed. Also, reasons against purchasing smart farming are similar. High investment costs are a significant reason against purchasing smart livestock farming technology as well as in crop production.

The reasons why adopting Industry 4.0 technologies is a slow process in agriculture could be classified as lack of technical understanding, lack of sufficient user experience, and costs with mostly no direct return on investment.

Nevertheless, constant connectivity is a prerequisite for adopting and applying Agriculture 4.0 technologies, like IoT systems, which are rarely mentioned in the research. Robust broadband internet pathways are especially required for real-time data transmission, a significant characteristic of smart farming. The United States and most countries of the European Union still lack a trustworthy internet connection (BERNHARDT ET AL.). The importance of this topic is shown by developing an EU digital transition strategy to promote sustainable, digital, and productive agriculture in the EU (EUROPEAN COMMISSION 2024a). The necessity of such a strategy is reflected in the answers given by the participants in the section "Applied smart farming technologies," where they rated the internet speed and mentioned the available connectivity on the farm and farmland. Most farmers in both regions rated the internet speed as reasonable and medium satisfying. On the farm, internet connectivity is available for most farmers in both areas. Therefore, in the EU, 14% of all European participants mentioned no internet connectivity on their farm, which reflects the lack of broadband internet pathways. Further, in the United States, around 7% don't have internet access on their farm, which is less compared to the EU. Nevertheless, this also indicates a lack of broadband access, as Bernhardt et al. 2021 mentioned (BERNHARDT ET AL.). Reliable internet connectivity is needed on the farmland for real-time data transmission for smart farming technologies, such as yield mapping and fertilizer or pesticide application rates. However, most EU and USA farmers have either partial internet connection on their agricultural land or no internet connectivity. In the USA and the EU, around 53% of the participants mentioned having partially available internet connectivity. This means smart farming technology couldn't be used correctly in every arable land, especially crop production. In this context, the proportion of arable land without connectivity would be interesting, but the survey didn't ask this. However, it is known that 7,8% of European and 17,9% of American farmers have no internet connection on any farmland. Again, this reflects the lack of a covering network in both regions, especially in agricultural and rural areas. In those areas, smart farming technologies couldn't be used correctly with all their functionality.

7. Conclusion

Summarizing the experiences and results of this online survey, the Methodology is critical but a quick method to get answers from a widespread target group. The questionnaire design allowed farmers to answer only the necessary questions related to their operation. Also, the stated non-comparability of different surveys leads to a new and uniform survey to compare the United States and the European Union's agriculture. The survey participants reflected mostly the common farm types of the regions, and trends could be seen despite the small number of participants. Confirming farm size and use of smart farming technologies trends are seen like those seen in different surveys.

The results highlighted that although the general conditions in agriculture in the political and structural context are different, most participating farmers from the USA and the EU see smart farming technologies as a way to face their main challenges. Even though the classification of the challenges for agriculture is sometimes considered in different directions, smart farming technologies were rated to face them and not as an additional challenge. This led to the statement that farmers see advantages in the Agriculture 4.0 technologies, which the regular self-driven search of information underlines.

The answers also show that American farmers are more business-orientated by rating the influence on running costs and income higher than the EU climate change and environmental effects were rated lower. So, in the United States, the return on investment is significant for purchasing smart farming technology, while in Europe, the environmental effects and more flexible work time are substantial. In both regions, high investment costs and the farm structure are the significant reasons against purchasing smart farming technologies.

The major criticisms about the known smart farming technologies for crop production and livestock production are, on the one hand, unreliable and insufficient user-friendliness and, on the other hand, a highly required technical understanding to use smart farming technologies. Two conclusions can be drawn from this. One is on the developers' side. A possible solution to these criticisms and to push the adoption of smart farming technologies is a more intuitive human-machine interface. This needs to be developed to increase user-friendliness and reduce the feeling that a high technical understanding is required. The other side is in an educational context to improve the technical knowledge of the farmers in the context of smart farming technologies. This raises the question of what kind of education and training is needed. Do farmers need fundamental knowledge of the technical background of the smart farming technology they use, or do they need more training from special trainers or teachers with basic knowledge of technology but only training the farmer in the required functionalities for their operation?

Those problems are not regional; they seem general for the modern agricultural engineering industry and farmers in the context of Agriculture 4.0 technologies. They need to be solved to support smart farming in the future.

Another less focused problem is the lack of internet connectivity, especially on farmland. This is also a problem in both regions and needs to be fixed by the governments. Private provider solutions are available, but those make the smart farming technology even more expensive and increase investment costs, potentially preventing farmers from acquiring smart farming technology (BERNHARDT ET AL.). Suppose the expansion of network connectivity isn't possible. In that case, alternative technologies like satellite-based internet access need to be supported where possible and maybe promoted financially for smart farming technologies to push the adaptation.

In conclusion, farmers, especially the next generation, see smart farming technology as a positive support for managing their farms and facing future challenges. Nevertheless, there is a lack of knowledge about the technology and user-friendliness, and reliable connectivity. Those major problems need to be solved to push the adoption.

When those problems are solved, the research potential, especially on-farm research in cooperation with farmers, is huge. It could also be an approach to improve and develop further smart farming technologies leading to economic, ecological, and socially sustainable agriculture facing future challenges in a global context, starting in the leading regions like the European Union and the United States of America.

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9. Appendix

The surveys were converted to a pdf document and sent separately.

10. Eidstattliche Erklärung

Hiermit versichere ich eidstattlich, dass ich die vorliegende Arbeit selbstständig und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Alle Stellen, die wörtlich oder sinngemäß aus Veröffentlichungen entnommen sind, wurden als solche kenntlich gemacht. Die Arbeit wurde in gleicher oder ähnlicher Form keiner anderen Prüfungsstelle vorgelegt.

Freising, 28.08.2024; Christina Sebald

Ort, Datum, Unterschrift

11. Statutory declaration

I declare on oath that I have written this thesis independently and without using any aids other than those specified. All passages taken verbatim or in spirit from publications have been identified as such. The thesis has not been submitted in the same or a similar form to any other examining body.

Freising, 28.08.2024; Christina Sebald

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