

REGULATION OF PRECISION FARMING IN EU COUNTRIES

REGULÁCIA PRESNÉHO POĽNOHOSPODÁRSTVA V KRAJINÁCH EÚ

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I Introduction

The agricultural sector in the European Union (EU) is undergoing a transformative shift driven by the adoption of precision farming technologies. These innovations, including satellite imagery, GPS-guided equipment, and data analytics, enable farmers to optimize resource use, increase productivity, and minimize environmental impact⁽¹⁾. Precision farming encompasses a variety of technologies and practices that allow for more precise application of inputs such as water, fertilizers, and pesticides. The ability to monitor and manage agricultural processes with unprecedented accuracy leads to improved yields, reduced waste, and less environmental degradation.

Despite these advantages, the rapid integration of precision farming technologies presents regulatory challenges that must be addressed to ensure their safe and effective use. Regulatory frameworks must adapt to the unique characteristics of precision agriculture,

including issues related to data privacy, technology interoperability, and environmental sustainability. The transformation of the agricultural sector through precision farming technologies marks a critical juncture in EU agrarian law. This paper contributes to the discourse by evaluating the regulatory frameworks governing these innovations, focusing on environmental impacts, economic implications, and regional case studies. By exploring the intersection of technology, sustainability, and law, the research underscores the significance of precision farming in achieving the EU's broader objectives of environmental protection and agricultural efficiency. Insights are also given into harmonizing EU regulations to ensure equitable and sustainable growth across member states.

1 The Regulatory Framework for Precision Farming in the EU

The regulatory framework for precision farming in the EU is shaped by various policies and directives aimed at promoting sustainable agriculture while

1 Boehlje and Kelsey (2021).

Abstract (EN)

This paper examines the regulation of precision farming in the countries of the European Union (EU), focusing on technological innovations, environmental impacts, and case studies from various member states. Precision farming, which utilizes advanced technologies to optimize agricultural practices, presents significant opportunities for enhancing productivity and sustainability. However, the integration of these technologies raises regulatory challenges that must be addressed to ensure safe and effective implementation. By analysing the regulatory frameworks and practices in different EU countries, this paper aims to identify best practices and propose recommendations for harmonizing regulations across the EU in order to support the growth of precision agriculture.

Keywords (EN)

precision farming, EU regulation, environmental sustainability, technological innovation, case studies

Abstrakt (SK)

Príspevok sa zaoberá reguláciou presného poľnohospodárstva v krajinách Európskej únie (EÚ) so zameraním na technologické inovácie, vplyvy na životné prostredie a prípadové štúdie z rôznych členských štátov. Presné poľnohospodárstvo, ktoré využíva pokročilé technológie na optimalizáciu poľnohospodárskych postupov, predstavuje významné príležitosti na zvýšenie produktivity a udržateľnosti. Integrácia týchto technológií však prináša regulačné problémy, ktoré je potrebné riešiť, aby sa zabezpečila bezpečná a účinná implementácia. Analýzou regulačných rámcov a postupov v rôznych krajinách EÚ sa tento dokument zameriava na identifikáciu osvedčených postupov a návrh odporúčaní na harmonizáciu predpisov v celej EÚ s cieľom podporiť rast presného poľnohospodárstva.

Kľúčové slová (SK)

presné poľnohospodárstvo, regulácia EÚ, environmentálna udržateľnosť, technologické inovácie, prípadové štúdie

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ensuring food safety and environmental protection. The Common Agricultural Policy (CAP) plays a central role in this framework by providing financial support to farmers who adopt innovative and sustainable practices⁽²⁾. Under the CAP, farmers are encouraged to invest in precision farming technologies through subsidies and grants, facilitating the transition towards more efficient and environmentally friendly agricultural practices⁽³⁾.

The regulation of precision farming is viewed differently by various stakeholders. Farmers often express concerns about the high costs of technology and data management challenges, though many acknowledge its potential to improve efficiency. Regulators aim to create frameworks balancing innovation, environmental safety, and data privacy. Activists focus on the social and environmental implications, emphasizing the need to safeguard smallholder farmers and biodiversity. Technological Companies advocate for supportive policies that encourage innovation and address interoperability challenges^{(4),(5)}.

Small and medium-sized enterprises (SMEs) in the agricultural sector face significant financial challenges in adopting precision farming technologies due to the high costs of equipment, training, and infrastructure upgrades. The CAP of the EU addresses these concerns by providing subsidies and grants designed to encourage the adoption of innovative and sustainable agricultural practices. By linking financial support to the implementation of environmentally friendly technologies, CAP plays a pivotal role in reducing barriers to entry for SMEs while promoting sustainability.

The CAP has undergone reforms that increasingly emphasize environmental sustainability and climate change mitigation. The introduction of the “green architecture” of the CAP highlights the need for practices that contribute to biodiversity and the reduction of greenhouse gas emissions⁽⁶⁾. Farmers adopting precision farming practices can access specific funds tied to environmental outcomes, reinforcing the importance of sustainability in agricultural policy.

Precision farming technologies also have a lifecycle, i.e. stages from technology development to environmental and economic impact as presented by Figure 1 below.

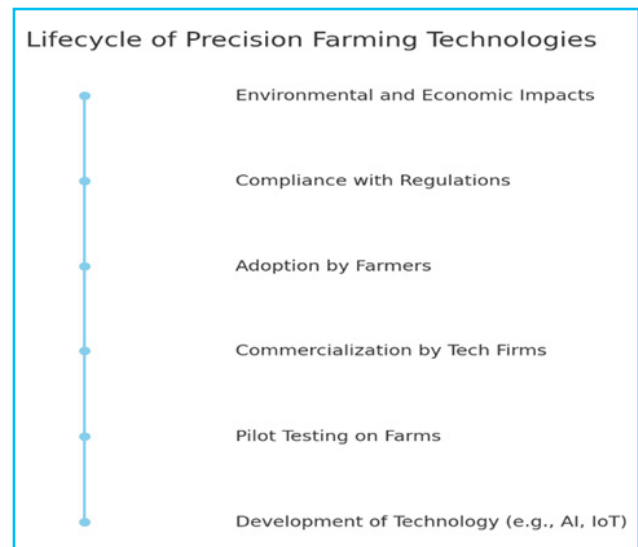


Figure 1 Stages of precision farming technologies
Source: authors' own compilation, 2024

Additionally, the EU has established regulations concerning the use of pesticides and fertilizers, which directly impact precision farming practices. The Sustainable Use of Pesticides Directive (2009/128/EC) aims to minimize the risks and impacts of pesticide use on human health and the environment. This directive emphasizes the importance of integrated pest management (IPM) and encourages the adoption of precision farming technologies to optimize pesticide application⁽⁷⁾. However, the implementation of these regulations varies across member states, leading to discrepancies in how precision farming is practiced and regulated. In some cases, member states have developed additional national regulations that may be more stringent than EU directives, creating a complex landscape for farmers operating in multiple jurisdictions⁽⁸⁾.

Furthermore, the General Data Protection Regulation (GDPR) introduces challenges related to data privacy and ownership in precision farming. As farmers increasingly rely on data-driven technologies, concerns about the collection, storage, and sharing of personal and agricultural data must be addressed to ensure compliance with GDPR and protect farmers' rights⁽⁹⁾. This regulation necessitates that data handling practices in precision agriculture be transparent and secure, which can be a significant barrier to innovation. Ensuring that data is used responsibly while still allowing farmers to benefit from its insights is a crucial aspect of developing effective regulations in this space.

2 European Commission (2021).

3 Lichtenberg (2018).

4 Karunathilake et al. (2023).

5 Faupel et al. (2023).

6 European Commission (2021).

7 European Commission (2009).

8 Zhou and Zhang (2021).

9 *Ibid.*

The complexities of these regulations highlight the need for a cohesive and integrated approach to policy development in the EU. Policymakers must work collaboratively with stakeholders, including farmers, technology providers, and environmental organizations, to create a regulatory environment that fosters innovation while addressing safety and environmental concerns⁽¹⁰⁾.

2 Technological Innovations and Regulatory Challenges

Technological advancements in precision farming encompass a wide range of innovations, including satellite-based technologies, sensors, drones, and data analytics platforms. These technologies are designed to provide farmers with precise information about their fields, allowing them to make data-driven decisions regarding resource allocation⁽¹¹⁾. For example, Global Positioning System (GPS) technology enables farmers to apply fertilizers and pesticides at optimal rates and locations, significantly reducing excess application and environmental harm⁽¹²⁾. Technologies like variable rate application (VRA) allow farmers to adjust the quantity of inputs based on specific field conditions, leading to cost savings and environmental benefits.

Despite the advantages, the rapid integration of these technologies into agricultural practices presents numerous regulatory challenges. One of the primary concerns is ensuring the safety of these technologies for agricultural use. For instance, drones used for aerial surveillance must adhere to strict aviation regulations to ensure they do not interfere with manned aircraft or violate privacy rights⁽¹³⁾. The European Union Aviation Safety Agency (EASA) has developed guidelines for drone usage, but these regulations must be continuously updated to keep pace with technological advancements⁽¹⁴⁾. The emergence of new drone technologies necessitates ongoing dialogue among regulators, manufacturers, and users to ensure that safety measures are both effective and practical.

Moreover, regulatory frameworks must address liability issues related to precision agriculture technologies. Questions surrounding liability in cases of malfunction or inaccurate data reporting can create hesitancy among farmers to adopt new technologies⁽¹⁵⁾. Establishing clear guidelines regarding accountability and risk management is essential to foster an

environment conducive to innovation⁽¹⁶⁾. For example, if a precision farming system fails to deliver accurate data, determining who is responsible for losses – be it the farmer, the technology provider, or another entity – can be complicated. This issue necessitates the development of comprehensive legal frameworks that clarify these responsibilities.

Recent studies highlight the evolving landscape of precision farming regulation in the EU. For instance, researchers emphasize the role of technological innovations such as IoT, drones, and AI in enhancing productivity while meeting sustainability goals⁽¹⁷⁾. Another focus is the institutional challenges posed by uneven adoption rates, particularly among smaller farms that face financial and technical barriers⁽¹⁸⁾. EU legislative initiatives, such as the CAP 2023–2027, have integrated Agricultural Knowledge and Innovation Systems (AKIS) to foster collaboration between stakeholders and support technology adoption across diverse agricultural contexts⁽¹⁹⁾.

Interoperability poses another significant challenge within the precision farming sector. The fragmented nature of agricultural technology development means that many systems are not compatible with one another, which can limit the effectiveness of data integration and sharing⁽²⁰⁾. Farmers may face difficulties in aggregating data from multiple sources, which can hinder their ability to make informed decisions. The EU can play a pivotal role in developing common standards that promote interoperability among different precision farming tools, thereby enhancing farmers' ability to utilize these technologies efficiently⁽²¹⁾. Collaborative initiatives that involve multiple stakeholders can lead to the creation of integrated systems that facilitate data sharing and improve overall agricultural performance.

3 Environmental Impact and Sustainability

The implementation of precision farming practices has profound implications for environmental sustainability. By utilizing technology to apply inputs more accurately, farmers can significantly reduce the quantities of fertilizers, pesticides, and water used, which contributes to lower pollution levels in soil and waterways⁽²²⁾. For example, precision irrigation systems allow farmers

10 Keszthelyi et al. (2021).

11 Keszthelyi et al. (2021).

12 Schnitkey and Roberts (2021).

13 Griffiths and Moulton (2020).

14 EASA (2021).

15 Boehlje and Kelsey (2021).

16 Lichtenberg (2018).

17 Faupel et al. (2023).

18 Masi et al. (2022).

19 Karunathilake et al. (2023).

20 Zhou and Zhang (2021).

21 Keszthelyi et al. (2021).

22 López-Ridaura et al. (2019).

to deliver water only where it is needed, minimizing runoff and conserving water resources⁽²³⁾. This not only enhances agricultural efficiency but also supports the EU's commitment to sustainable water management under the Water Framework Directive⁽²⁴⁾. Effective water management is crucial, particularly in areas facing water scarcity, and precision farming technologies provide viable solutions.

Climate change and resource depletion are driving the urgency to regulate precision farming effectively. Precision technologies enable resource-efficient practices, such as precision irrigation and targeted fertilizer application, which reduce emissions and mitigate resource scarcity⁽²⁵⁾. However, regulations must evolve to ensure equitable access to these technologies, fostering resilience against climate impacts⁽²⁶⁾.

The environmental benefits of precision farming align closely with the EU's Green Deal and Farm to Fork Strategy, which emphasize the transition to a sustainable and resilient agricultural system. These technologies enable targeted application of resources, reducing chemical runoff and greenhouse gas emissions, which directly support the EU's goal of climate neutrality by 2050. Furthermore, initiatives such as the Sustainable Use of Pesticides Directive encourage precision techniques to minimize environmental harm, highlighting the symbiotic relationship between technological innovation and regulatory frameworks in achieving environmental sustainability.

Furthermore, precision farming can enhance biodiversity by reducing the need for chemical inputs that can harm non-target organisms. Implementing integrated pest management (IPM) strategies, which are often facilitated by precision technologies, allows farmers to minimize pesticide usage while effectively controlling pests⁽²⁷⁾. The ability to monitor pest populations in real-time enables farmers to apply control measures only when necessary, leading to a decrease in pesticide applications and a more balanced ecosystem.

However, the environmental benefits of precision farming are contingent upon the regulatory framework that governs its implementation. Regulations must not only promote the adoption of these technologies but also ensure that they are applied in a manner that aligns with broader environmental goals. This includes monitoring the environmental impacts of precision farming practices to ensure they contribute positively to

biodiversity and ecosystem health⁽²⁸⁾,⁽²⁹⁾. Policymakers must establish clear guidelines and monitoring systems to evaluate the effectiveness of precision farming practices in achieving environmental sustainability objectives.

Research indicates that adopting precision farming technologies can lead to a more sustainable agricultural sector, but this requires supportive policies and frameworks at the EU level⁽³⁰⁾. The EU's Green Deal and Farm to Fork Strategy are examples of initiatives aimed at promoting sustainable agricultural practices, with an emphasis on innovation and technology adoption to address environmental challenges⁽³¹⁾. These strategies highlight the EU's commitment to reducing greenhouse gas emissions from agriculture and fostering sustainable farming practices, and precision farming is positioned as a key tool in achieving these goals.

In conclusion, precision farming has the potential to significantly reduce the environmental footprint of agriculture. Still, this potential must be harnessed through effective regulations that encourage the adoption of these technologies while safeguarding environmental integrity.

4 Case Studies of EU Member States

The adoption and regulation of precision farming technologies vary widely among EU member states. Precision farming technologies are adopted at varying levels across EU member states due to differences in regulatory environments, technological infrastructure, and farming practices. For instance, Germany and the Netherlands have taken significant strides in integrating advanced tools like GPS and variable rate applications due to supportive government initiatives and robust technological ecosystems. In contrast, countries like Poland and Spain face uneven adoption rates due to regional disparities in funding, access to technology, and farmer education. These differences underscore the need for a harmonized EU policy framework that accounts for local conditions.

Germany stands out as a leader in the integration of precision farming technologies. The German government has actively supported research and development in this sector through initiatives such as the Agricultural Innovation Program⁽³²⁾. German farmers are utilizing data analytics, GPS technology, and variable rate applications to optimize yields and

23 Griffiths and Moulton (2020).

24 European Commission (2000).

25 Faupel et al. (2023).

26 Masi et al. (2022).

27 European Commission (2009).

28 Lichtenberg (2018).

29 López-Ridaura et al. (2019).

30 Keszthelyi et al. (2021).

31 European Commission (2020).

32 Bundesministerium für Ernährung und Landwirtschaft (2019).

resource use⁽³³⁾. Furthermore, stringent regulations on pesticide use necessitate the implementation of precision technologies to comply with environmental standards, creating a strong incentive for adoption⁽³⁴⁾.

The Netherlands is another example where precision farming has gained significant traction, particularly in the greenhouse horticulture sector. Dutch farmers employ advanced climate control systems and precision irrigation technologies to maximize productivity while minimizing environmental impact. The Dutch government actively promotes sustainable agricultural practices through funding and support for technology adoption⁽³⁵⁾. The integration of precision farming in the Netherlands is also facilitated by strong collaborative networks between farmers, researchers, and technology providers, enhancing knowledge exchange and innovation⁽³⁶⁾.

In France, precision farming is increasingly recognized as a crucial component of sustainable agricultural practices. The French government has launched initiatives to support the adoption of precision technologies, particularly in cereal production. However, challenges remain, such as resistance among some farmers due to a lack of understanding or access to technology⁽³⁷⁾. Regulatory efforts are being made to provide training and resources to facilitate the transition towards precision agriculture, ensuring that farmers are equipped to leverage these technologies effectively.

Spain also exemplifies the potential of precision farming, particularly in its vast fruit and vegetable sectors. Spanish farmers are increasingly utilizing precision irrigation and monitoring systems to manage water usage efficiently and respond to environmental challenges such as drought⁽³⁸⁾. The Spanish government has launched initiatives to support farmers in integrating precision technologies into their practices, although the uptake remains uneven across different regions and types of farming operations⁽³⁹⁾.

Similarly, Poland is beginning to embrace precision farming technologies, supported by EU funding aimed at modernizing its agricultural sector⁽⁴⁰⁾. While there are challenges related to infrastructure and farmer training, the Polish government is actively promoting precision agriculture as a means to enhance productivity and sustainability in the country's diverse agricultural landscape.

In Italy, precision agriculture is gaining traction, especially in regions known for viticulture. Italian vineyards are adopting precision viticulture practices to monitor and manage grape quality, optimize irrigation, and reduce chemical inputs⁽⁴¹⁾. The Italian government has recognized the potential of precision agriculture in enhancing the competitiveness of the wine sector and has implemented policies to support technology adoption among grape growers.

Finland is exploring precision farming practices to enhance the sustainability of its agriculture. Finnish farmers are utilizing precision tools for soil monitoring and nutrient management, contributing to reduced fertilizer use and improved soil health⁽⁴²⁾. The Finnish government promotes research initiatives to develop precision technologies tailored to the unique climatic and soil conditions of the country.

Austria has also made significant strides in precision farming by focusing on organic agriculture and sustainable practices. The Austrian government has established programs that promote precision technologies among organic farmers, aiming to enhance productivity while adhering to organic standards⁽⁴³⁾. The integration of precision tools in organic farming demonstrates the adaptability of these technologies across different agricultural systems.

In Denmark, precision farming is increasingly integrated into conventional and organic farming practices, supported by strong government policies and research initiatives. Danish farmers are adopting precision technologies to enhance nutrient management, leading to reduced fertilizer use and improved environmental outcomes⁽⁴⁴⁾. The Danish government's commitment to sustainability and innovation fosters an environment conducive to the growth of precision farming.

Lastly, Ireland is focusing on precision farming to enhance the efficiency of its livestock sector. Irish farmers are utilizing precision technologies for pasture management, which helps optimize grazing patterns and improve animal health⁽⁴⁵⁾. The Irish government has implemented strategies to promote precision agriculture as a means of enhancing farm productivity while reducing the sector's environmental impact.

The recommendations outlined in the paper are deeply informed by case studies that illustrate diverse regulatory and adoption practices across member states. For example, the success of Germany's Agricultural Innovation Program provides a blueprint

33 Keszthelyi et al. (2021).

34 Schnitkey and Roberts (2021).

35 Uthayakumar et al. (2020).

36 Lichtenberg (2018).

37 Keszthelyi et al. (2021).

38 Uthayakumar et al. (2020).

39 Lichtenberg (2018).

40 Keszthelyi et al. (2021).

41 Lichtenberg (2018).

42 Keszthelyi et al. (2021).

43 Uthayakumar et al. (2020).

44 Keszthelyi et al. (2021).

45 Schnitkey and Roberts (2021).

Table 1 Challenges and solutions in precision farming

Challenges	Precision farming solutions	Regulatory approaches
Climate change	targeted resource use to reduce emissions	incentives for climate-smart farming
Resource depletion	precision irrigation and soil monitoring	mandatory resource tracking
Uneven tech adoption	subsidies and knowledge transfer	harmonized standards under CAP

Source: authors' own editing

for integrating precision farming, while the challenges faced by regions with limited infrastructure highlight the need for targeted EU interventions. By connecting these examples to actionable recommendations, the paper offers a practical framework for policymakers to address disparities and foster collaborative growth across the EU.

In conclusion, the case studies from various EU member states highlight the diverse approaches to regulating and adopting precision farming technologies. While some countries have made significant strides in integrating these practices, challenges remain in terms of infrastructure, farmer education, and regulatory coherence. The EU's regulatory framework must support knowledge exchange and best practices to facilitate the widespread adoption of precision farming across all member states. Table 1 integrates challenges like climate change and resource depletion, precision farming solutions, and corresponding regulatory approaches.

II Conclusion

In summary, the regulation of precision farming in EU countries presents both significant opportunities and challenges. As precision agriculture technologies continue to evolve, they offer the potential to enhance productivity, reduce environmental impacts, and improve the sustainability of agricultural practices. However, effective regulatory frameworks are essential to ensure these technologies are integrated safely and equitably across different member states.

The analysis highlights the need for a cohesive approach to policy development, focusing on harmonizing regulations to promote innovation while safeguarding environmental integrity. Case studies from various EU countries illustrate the diverse strategies and practices adopted to regulate precision farming, underscoring the importance of collaborative efforts among policymakers, farmers, and technology providers.

Ultimately, the successful integration of precision farming technologies within the EU will depend on the ability to adapt regulations to the unique challenges posed by these innovations while fostering an environment conducive to sustainable agricultural

development. The harmonisation of regulations, better alignment of interoperability issues and promoting innovation would be beneficial for all member states. As the EU moves forward, continued support for research, education, and knowledge exchange will be crucial in realizing the full potential of precision agriculture in contributing to a more sustainable and efficient food system.

Similar to other research, our own research also involves some points to be discussed later. Future research could explore developing unified regulatory standards for interoperability and data governance across the EU, investigating the socio-economic impacts of precision farming on rural communities, assessing long-term environmental outcomes from precision farming practices and enhancing frameworks like AKIS to better integrate local knowledge and global innovations

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