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Czech farmers' perspectives on sustainable agriculture and water management: Implications for climate change adaptation

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ABSTRACT

Climate change significantly challenges agricultural water management, requiring a shift to sustainable practices. This study examines Czech farmers' attitudes towards sustainable agriculture and water management based on a survey of 1176 farmers. We use traditional and innovative methods, such as factor analysis, ANOVA, and machine learning, to uncover patterns in the data. Additionally, we apply AI language model methods to reclassify open-ended responses, enhancing our understanding of farmers' attitudes. Results show that 98.4 % of farmers recognize the importance of water retention, and 79.2 % are willing to adopt nature-based measures. Organic farmers are more interested in water management measures than conventional farmers ($p < 0.01$). A significant majority (91.7 %) of farmers perceive climate change as a threat. Interestingly, our findings reveal a weak but significant negative correlation ($r = -0.11$, $p < 0.05$) between farm size and willingness to invest in water management measures, which contrasts with international trends where larger farms typically show greater willingness to invest. This divergence highlights the unique structural and historical context of Czech agriculture. Our innovative analytical approaches uncover complex relationships between various factors influencing farmers' attitudes, providing a nuanced view of the issue. These findings offer essential insights for developing targeted agricultural policies and strategies for climate change adaptation in the Czech Republic, highlighting the need for differentiated approaches based on farm characteristics and regional specifics.

1. Introduction

1.1. Context of the study

Climate change presents a significant challenge to agriculture globally, particularly in water management, with increasing extreme events impacting agricultural production and landscape stability (Trnka et al., 2017; Valencia Cotera et al., 2023; Žalud et al., 2011). Sustainable and effective agricultural water management are therefore crucial for climate change adaptation. European agricultural policy increasingly emphasizes sustainable practices in response to climate change and societal priorities, highlighting the need for agroecological approaches, efficient water use, and agricultural water management reforms (Seijger and Hellegers, 2023; Trnka et al., 2011; Kędziora and Olejnik, 2019; Vargas-Amelin and Pindado, 2014). Research underscores the importance of maintaining water balance and adapting water management to regional climate risks.

The Czech Republic, like other European nations, faces increasing pressure to adapt agricultural practices. Agriculture occupies over 50.0 % of the Czech landscape, providing essential ecosystem services including climate regulation and water retention (ÚZEI, 2023). However, a substantial portion of agricultural land is also waterlogged (MZe, 2021), presenting specific water management challenges and opportunities. Czech agricultural policy aligns with European trends, increasingly supporting environmental protection and water retention measures through programs like the Rural Development Program (Mze, EC, 2024). These programs address the historical decline in landscape water retention capacity stemming from past agricultural practices (Kulhavý et al., 2007; Petřík et al., 2015).

The current state of the Czech landscape's water retention is shaped by long-term historical development. Since the 1950s, prioritizing short-term economic gains over long-term sustainability led to a decline in landscape quality and water retention. Extensive 20th-century drainage significantly contributed to this decline (Petřík et al., 2015; Kulhavý et al., 2007). However, recent research highlights the potential for restoring historical landscape features like ponds and wetlands,

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particularly from the mid-19th century (Frajer et al., 2021; Pavelková et al., 2016), as a nature-based approach to enhance water retention and climate change resilience. Today, Czech agriculture faces the urgent need to adapt traditional practices and adopt new water management strategies to address climate change risks, particularly drought and water scarcity (Müllerová et al., 2024). Limited water resources, geographical watershed boundaries, and reliance on atmospheric precipitation further exacerbate these challenges (Zelenakova et al., 2020). The most vulnerable areas in the Czech Republic are facing combined risks of drought, soil erosion, and local floods (Trnka et al., 2016), with climate change projections indicating further temperature increases and altered precipitation patterns (Trnka et al., 2017; Žalud et al., 2011).

In this context, nature-based solutions, particularly wetlands and natural water retention measures (NWRM) in agricultural landscapes, are increasingly recognized as effective tools for sustainable water management (Keesstra et al., 2018; Pistocchi, 2022; Sušnik et al., 2022). Wetlands offer multiple benefits, acting as natural water reservoirs, supporting biodiversity, and contributing to water purification and local climate regulation (Hefting et al., 2013; Mitsch, 2016; Zedler, 2003). Understanding farmers' perspectives on NWRM implementation, considering cost-effectiveness and maintenance (Collentine and Futter, 2018; Galler et al., 2015). This study aims to contribute to this understanding by exploring Czech farmers' attitudes towards sustainable agriculture and water management, with a specific focus on wetlands and waterlogged areas.

1.2. Current state of research

Farmers' attitudes are increasingly recognized as a key factor in the adoption of sustainable agricultural practices and climate change adaptation measures. Studies highlight the variability of farmers' perceptions of climate change and their willingness to adopt sustainable practices across different regions (Mitter et al., 2019; Nguyen et al., 2019). Moreover, research by Falcão et al. (2024) emphasizes the global dimension of the issue of farmers' attitudes by focusing on the perception of soil health in various European countries and China. Prokopy et al. (2015) crucially highlight the perception of risks associated with climate change as a driver of farmers' willingness to adapt, while Iglesias and Garrote (2015) specify these risks in agriculture, for example, water scarcity and extreme events. In sustainable agriculture, concepts like wetlands are gaining importance, particularly regarding their biodiversity, as demonstrated by Thiere et al. (2009) and Brinson and Malvárez (2002). Furthermore, the importance of wetlands in agricultural landscapes for local climate regulation is increasingly emphasized, as Huryna et al. (2014) point out, recommending wetland restoration as an effective measure for managing the thermal balance of the landscape.

In CZE, the issue of water resources and their management is addressed by Sedmidubský and Grmelová (2018). Specifically, for the Czech context, the study by Malec et al. (2022) is relevant, focusing on the development of water management in Czech agricultural production between 1961 and 2019. An analysis of case studies from 14 different regions in Europe, illustrating various challenges and approaches to improving the landscape's water retention capacity, is presented by Magnier et al. (2024). Kročová and Kavan (2019) focus on international cooperation in water management in the border areas of CZE, and the issue of drained areas and the need for comprehensive measures in these areas in the context of climate change is addressed by Kulhavý and Fučík (2015). These studies form the foundation for our research, which aims to analyze Czech farmers' attitudes towards sustainable agriculture and water management measures in the context of climate change adaptation.

1.3. Research objectives

Based on the current state of research and the specific situation in CZE, our study aims to analyze the attitudes of farmers in CZE towards sustainable agriculture and water management measures, particularly focusing on the issue of waterlogged areas. To address this complex topic, we have identified the following specific objectives:

1. Analyze Czech farmers' attitudes towards sustainable agriculture and water management measures, including their willingness to implement specific water management practices.
2. Identify key factors influencing these attitudes, with a particular focus on the perception of climate change risks and the perceived importance of water management.
3. Analyze potential regional differences in farmers' attitudes and willingness.
4. Provide recommendations for the development of agricultural policies.

To achieve these goals, we conducted an extensive survey with 1176 respondents from across CZE. This methodology allows us to gain a comprehensive view of the issue across different regions and types of agricultural enterprises. In the following sections, we present the detailed methodology of our research, including the questionnaire design and data analysis methods. We then present the key findings of the analysis and discuss their implications for the future of water management and wetland management in Czech agriculture in the era of climate change. Finally, we provide policy recommendations and suggest directions for future research in this area.

2. Methods

This study employed a mixed-methods approach to analyze Czech farmers' attitudes towards sustainable agriculture and water management. Inspired by Sattler and Nagel (2010), our methodology combined quantitative analysis of survey data with qualitative analysis of open-ended responses using machine learning techniques. The process involved online questionnaire data collection, rigorous data preparation and cleaning, and multilevel statistical analysis (visualized in Fig. 1). This comprehensive approach aimed to identify key factors influencing farmers' attitudes and to provide nuanced insights into the complex dynamics of sustainable agriculture and water management in the Czech Republic. The following subsections detail each phase of our methodology.

2.1. Data collection

Data were collected through an online survey distributed through the State Agricultural Intervention Fund (SZIF), ensuring broad reach across Czech farmers. The survey was conducted from February 2023 to March 2024. Farmers received an email link via SZIF branches and participated voluntarily. Google Forms was used for questionnaire creation and management, streamlining data collection. This online approach yielded 1176 completed responses from diverse farm types and regions across the Czech Republic, providing a robust dataset for comprehensive analysis of farmers' attitudes.

The questionnaire consisted of two parts (see Appendix for full questionnaire). Part 1 focused on farmers' attitudes towards sustainable agriculture and water management practices, including closed, semi-closed, and open-ended questions (14, 4, and 1 respectively). These questions explored perceptions of landscape state, importance of sustainable agriculture, climate change impacts, and willingness to adopt water management measures (see Fig. 2 for overview of questions). Closed questions utilized Likert scales and categorical responses for quantitative analysis, while semi-closed and open-ended questions allowed for richer qualitative insights. Part 2 gathered data on farm characteristics and demographics using closed, semi-closed, and open-ended questions (8, 1, and 2 respectively), covering farm location, type, size, ownership, respondent roles, and education (Fig. 2). The questionnaire design balanced the need for quantifiable data with the

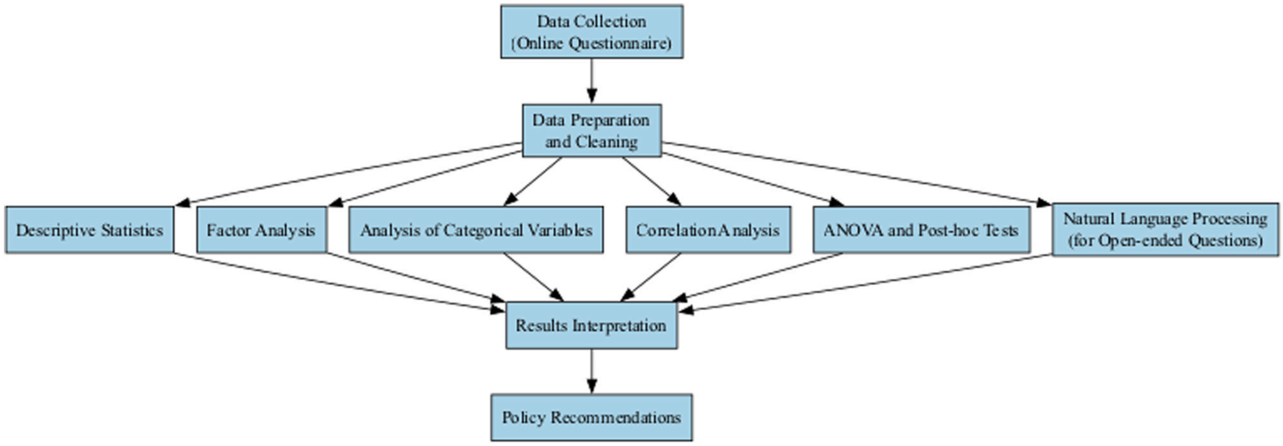

Fig. 1. Overview of the methodology for analyzing survey data on sustainable agriculture Practices.

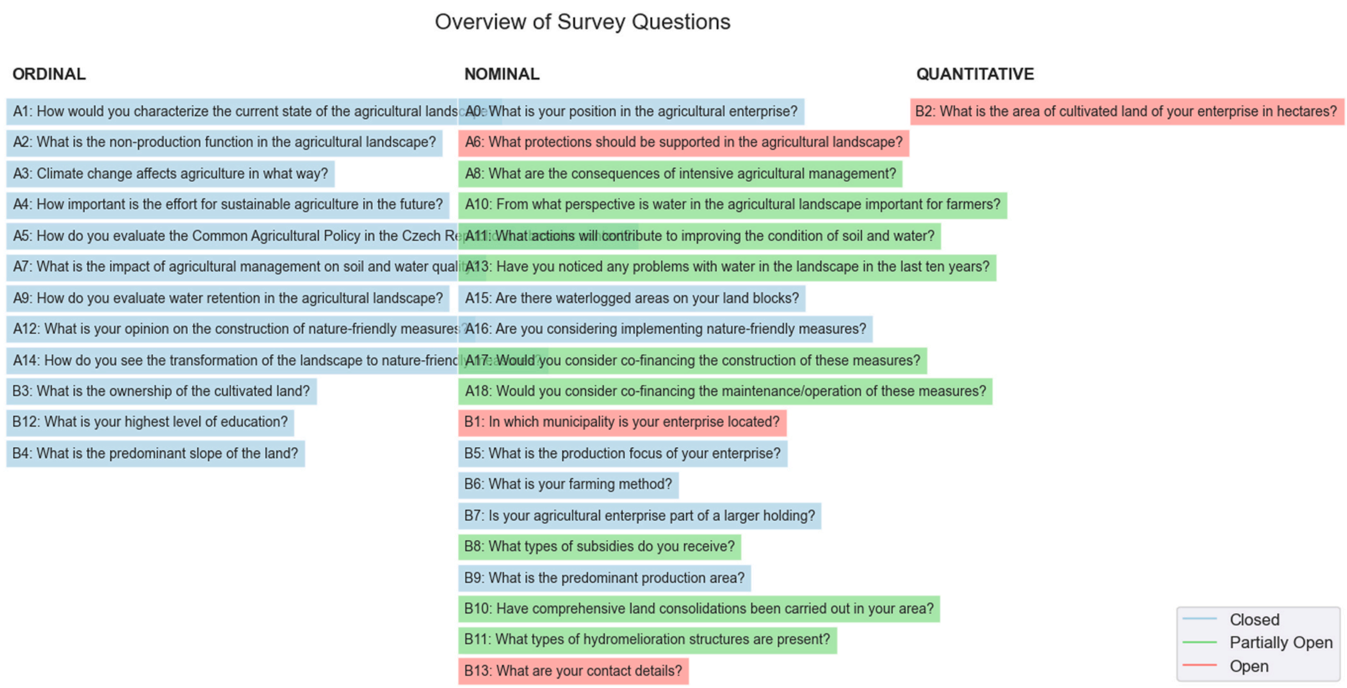

Fig. 2. Overview of questions in the questionnaire on sustainable agriculture and water management practices.

desire to capture nuanced farmer perspectives.

2.2. Data preparation and cleaning

To ensure data quality and reliability, collected data underwent rigorous preparation and cleaning, encompassing several key steps. These included: data formatting into uniform tables, data integrity checks to identify and correct input errors, geocoding to enable spatial analysis of regional differences (respondent distribution shown in Fig. 3), data cleaning to address missing values and outliers, and data transformation. Data transformation involved converting closed-ended questions to ordinal variables where appropriate and employing AI-powered semantic language models for efficient and objective reclassification of open-ended and semi-closed responses. This innovative approach, utilizing AI tools, was crucial for capturing nuances in qualitative data and enhancing the comprehensiveness of the analysis.

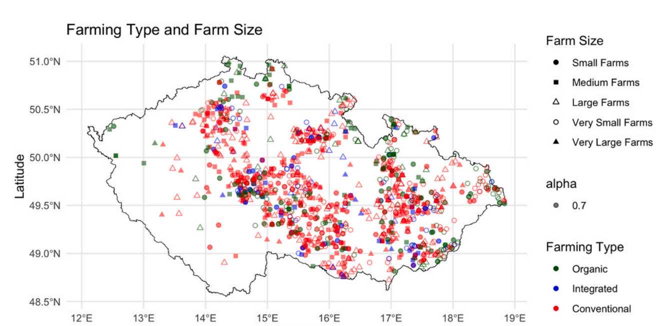

Fig. 3. Map of survey respondents' distribution within the CZE.

2.3. Statistical methods

Data analysis employed a comprehensive suite of statistical and machine learning techniques to address the research objectives.

Quantitative data were analyzed using a combination of standard statistical methods and more advanced techniques. Standard statistical techniques included descriptive statistics to summarize sample characteristics, Analysis of Variance (ANOVA), and Kruskal-Wallis test (for non-parametric data) to examine group differences, and correlation analysis (Pearson and Spearman coefficients) to assess relationships between variables. These methods provided foundational insights into the data and allowed for initial exploration of farmer attitudes and their relationships with farm characteristics.

To delve deeper into the underlying attitudinal structures, factor analysis (principal component method with varimax rotation) was employed. This method is particularly useful for identifying latent factors that explain the variance among a set of observed variables. In this study, factor analysis helped to uncover key attitudinal dimensions from the survey responses related to sustainable agriculture and water management. The optimal number of factors was determined using scree plot and elbow methods. Additionally, Multivariate Analysis of Variance (MANOVA) was conducted to examine how the individual numerical variables relate to the computed factors, providing greater insight into the relationships between observed variables and the identified latent factors.

For the analysis of qualitative data from open-ended survey questions, Natural Language Processing (NLP) methods were utilized. Specifically, a Czech-language Sentence Transformer model (Bednář et al., 2024) was used for text vectorization. This allowed for the transformation of textual responses into numerical vectors, enabling quantitative analysis of qualitative data. Following text vectorization, cluster analysis (K-means algorithm with elbow and silhouette score methods) was applied to segment and categorize the open-ended responses based on semantic similarity. This innovative approach using AI-powered methods allowed for a more objective and nuanced understanding of the qualitative data, complementing the quantitative findings.

Statistical significance was set at $\alpha = 0.05$. Analyses were primarily conducted in Python, with supplementary calculations in R. This multifaceted analytical approach enabled robust identification of complex patterns and relationships in farmers' attitudes towards sustainable agriculture and water management in the Czech Republic.

3. Results

3.1. Characteristics of survey respondents

Our sample of 1176 Czech farmers provided a diverse representation of the country's agricultural landscape. Respondents exhibited variety in agricultural practices: 51.7 % combined crop and livestock production, 36.7 % crop production only, and 11.6 % livestock only. Conventional farming predominated (65.6 %), followed by organic (23.6 %) and integrated (10.7 %). Farm sizes varied; 39.6 % managed over 50 % own land, 15.1 % under 10.0 %. Gentle slopes (3–5°) were most common (44.0 %), followed by moderate (5–7°, 25.6 %) and flat to slight slopes (1–3°, 25 %). Potato-growing region was most represented (36.1 %), followed by Sugar Beet (27.2 %), Mountainous (20.8 %), and Corn-growing (15.8 %). Respondents' education was diverse: 29.8 % university degree in agriculture, 21.4 % agricultural high school diploma, 15.8 % high school diploma in other field. For a detailed summary of these characteristics, please refer to Table A2 in the Appendix. Fig. 3 presents a spatial representation of the respondents' locations, while Fig. 4 illustrates the percentage distribution of farming methods within each production focus category.

3.2. Farmers' attitudes and perceptions

Perceptions of the agricultural landscape's condition were assessed through question A1 ("Characterize the current state of the agricultural landscape"). The survey revealed that a significant majority of farmers, specifically 75.9 %, rated the agricultural landscape as "satisfactory" or better. Looking at the detailed breakdown, 15.4 % considered it "very good," 32.5 % "good," and 27.9 % "satisfactory." However, a notable minority held less favorable opinions, with 19.2 % judging it "rather unsatisfactory" and 5.0 % "unsatisfactory."

Farming practices significantly influenced these perceptions. Organic farmers were notably more critical in their assessment of the landscape's state compared to conventional farmers ($p < 0.01$). This statistically significant difference suggests that organic farmers, possibly due to their deeper commitment to ecological principles, are more attuned to the shortcomings present in the current agricultural landscape. Furthermore, educational background also played a role in

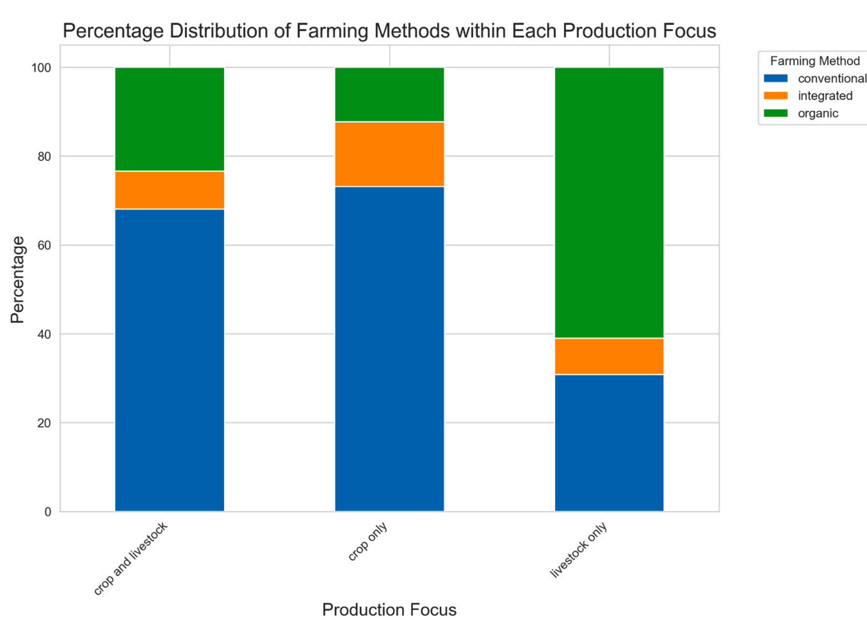

Fig. 4. Distribution of farming methods within each production focus. This stacked bar chart shows the percentage distribution of farming methods (conventional, integrated, organic) for each production focus category (crop and livestock, crop only, livestock only). The graph illustrates the prevalence of conventional farming across all production focus categories, while also highlighting the presence of organic and integrated farming methods in each category.

shaping perceptions. Respondents with a university education in non-agricultural fields tended to rate the landscape's condition lower than those with secondary agricultural education ($p < 0.05$), as illustrated in Fig. 5. This indicates that diverse educational backgrounds may lead to varying benchmarks for what constitutes a "satisfactory" agricultural landscape, with non-agricultural university education potentially fostering a more critical environmental perspective.

Moving beyond general landscape perception, the study explored attitudes towards sustainable agriculture. Here, a strong consensus emerged among Czech farmers regarding its importance. An overwhelming majority, 94.9 %, deemed non-productive landscape functions, such as biodiversity support and erosion control, as important or essential. Specifically, 58.7 % considered these functions "essential," while 36.2 % viewed them as "important." Similarly, when questioned about the future importance of sustainable agriculture efforts, 95.7 % of respondents rated it as very important or important. This further emphasizes the widespread recognition of the necessity for sustainable agricultural practices. Interestingly, a clear distinction arose between farmer types: organic and integrated farmers consistently placed greater importance on both non-productive functions and sustainable agriculture compared to conventional farmers ($p < 0.001$). This highly significant difference underscores a divergence in environmental values and priorities based on farming methods, with organic and integrated farming attracting farmers with stronger pre-existing pro-environmental attitudes. These findings are visually summarized in Fig. 6.

Finally, attitudes towards water management measures in the agricultural landscape were examined. Consistent with the previous findings, a strong consensus prevailed regarding the importance of these practices. An overwhelming majority, again 94.9 %, considered water retention in agricultural landscapes as important or essential. This widespread agreement highlights the recognized critical role of water management in sustainable agriculture. This recognition translated into a tangible willingness to act, as a significant portion of respondents, 65.1 %, expressed a willingness to co-finance the construction of water retention measures. Among those willing to contribute financially, the most common commitment was up to 10.0 % of the costs, indicated by 28.7 % of respondents, suggesting a general willingness to share financial responsibility, albeit with a preference for smaller contributions. Furthermore, mirroring the trends observed in other attitudinal questions, organic farmers consistently demonstrated greater interest and willingness to implement water management measures compared to conventional farmers ($p < 0.01$). This statistically significant difference reinforces the pattern of a stronger pro-environmental stance among organic farmers. Although the relationship is relatively weak, there is a significant negative correlation between farm size and willingness to invest in water management measures ($r = -0.11$, $p < 0.05$). This suggests a slight tendency for smaller farms to be more open to investing in water management infrastructure, though the relationship should be interpreted with caution given the low correlation coefficient. Key findings from descriptive statistics are summarized in Fig. 7.

3.3. Key factors influencing farmers' attitudes

This chapter investigates the primary factors, including those that are often latent or implicit, shaping farmers' attitudes towards sustainable agriculture and water management measures in the agricultural landscape. We then analyze the relationship between these identified factors and various characteristics of farms and farmers.

Our investigation aims to clarify the complex interplay between farmers' perceptions, their agricultural practices, and the broader context of sustainable land management. By identifying these key factors, we aim to provide insights that can inform policy development and the implementation of effective strategies for promoting sustainable agriculture and water management.

3.3.1. Factor analysis: identifying key attitudinal factors

Factor analysis was employed to identify underlying attitudinal factors. The scree plot method was used to determine the optimal number of factors, suggesting a three-factor model as appropriate for this dataset (Scree plot available in Appendix, Fig. A2). To categorize and name these factors, we employed a comprehensive approach, analyzing not only the patterns of factor loadings and correlations (visualized in Heatmap Fig. 8), but also the semantic content of individual survey items.

Based on this integrated analysis, we identified three key attitudinal factors:

1. Attitude towards Sustainable Agriculture and Landscape Protection
2. Willingness to Invest in Water Management Measures
3. Perception of Water Features in the Agricultural Landscape

These three factors collectively explained 39.3 % of the total variance in farmers' attitudes.

Horizontal axis: Attitudinal Factors identified through factor analysis

Factor 1: Attitude towards Sustainable Agriculture and Landscape Protection

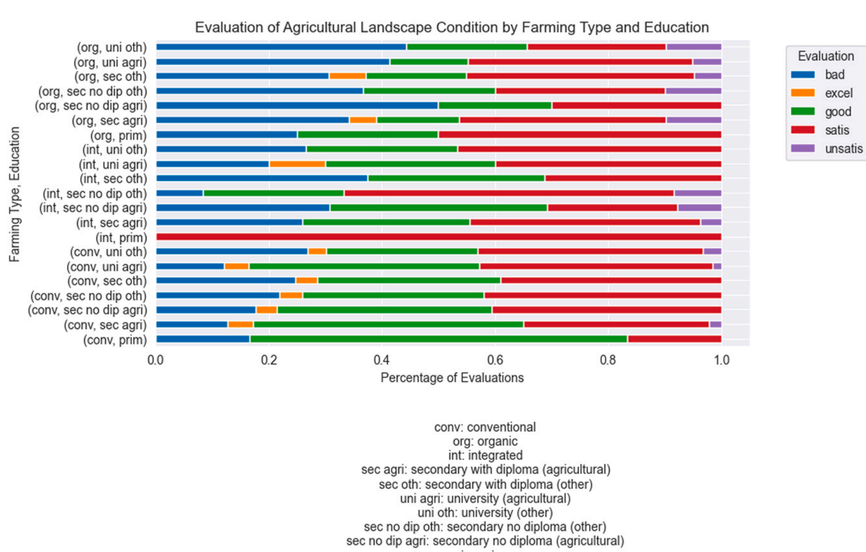

Fig. 5. Assessment of the agricultural landscape's condition based on farming type and educational background of respondents.

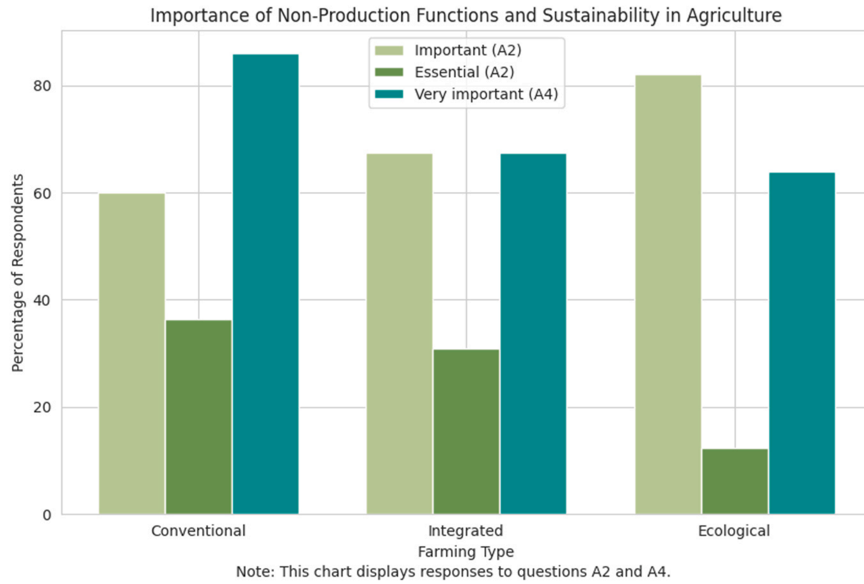

Fig. 6. Attitudes towards sustainable agriculture practices by type of farming (e.g., Organic, Conventional). Note: This chart displays responses to Question A2: "What is the non-production function in the agricultural landscape?" (Importance of Non-Production Functions) and Question A4: "How important is the effort for sustainable agriculture in the future?" (Sustainability Importance).

Factor 2: Willingness to Invest in Water Management Measures

Factor 3: Perception of Water Features in the Agricultural Landscape* *

Vertical axis: Survey Questions (Variables). Each row represents a specific question from the survey questionnaire (abbreviated question codes are used). For clarity, key question codes are expanded below with a brief description:

a7: What is the impact of agricultural management on soil and water quality?

a9: How do you evaluate water retention in the agricultural landscape?

a12: What is your opinion on the construction of nature-friendly measures?

a14: How do you see the transformation of the landscape to nature-friendly?

a15: Are there waterlogged areas on your land blocks?

a16: Are you considering implementing nature-friendly measures?

a17: Would you consider co-financing the construction of these measures?

a18: Would you consider co-financing the maintenance/operation of these measures?

b2: What is the area of cultivated land of your enterprise in hectares?

b3: What is the ownership of the cultivated land?

b5: What is the production focus of your enterprise?

See Fig. 2 for the full wording of survey questions.

3.3.2. *Influence of farm and farmer characteristics on attitudinal factors*

This section examines the influence of farm and farmer characteristics on the identified attitudinal factors (detailed statistical results in Appendix, Tab. A3). While most characteristics showed no statistically significant influence, notable trends emerged. Farming practices had a marginally significant effect on "Attitude towards Sustainable Agriculture and Landscape Protection" ($p = 0.067$), suggesting more positive attitudes among organic farmers. Farm size showed a marginally significant effect on "Willingness to Invest in Water Management Measures" ($p = 0.0610$), indicating more favorable attitudes among larger farms. Contrary to some previous studies (e.g., Smith and Sullivan, 2014), education level did not significantly influence attitudinal factors. However, complex influences related to farm holdings, land consolidation, and hydro-melioration structures were observed, suggesting nuanced relationships between farm characteristics and attitudes towards sustainable practices.

3.3.3. *Influence of farm characteristics on quantitative variables*

While our previous analysis of categorical variables showed limited influence, farm characteristics significantly impact quantitative variables. Farm size negatively correlates with willingness to invest in water management ($r = -0.11$, $p < 0.05$). Farming methods significantly shaped environmental awareness, with organic farmers showing higher awareness compared to conventional farmers ($p < 0.001$). Education level, particularly in agriculture, significantly impacts willingness to implement water management ($p < 0.001$). Region also plays a significant role: mountainous farms reported higher wetland occurrence; drier region farmers showed greater retention measure interest; and mountainous farms demonstrated higher willingness to implement water management, while corn-growing region farmers were less willing to invest in landscape water retention (all $p < 0.05$).

3.3.4. *Perception of climate change and its impact on attitudes towards sustainable practices*

Czech farmers widely recognize climate change as a significant threat (91.7 %), though perceptions of immediacy vary (Fig. 9). Perceived climate change threat significantly influenced attitudes towards sustainable practices. Farmers viewing climate change as a current threat showed higher willingness to implement water management measures ($p < 0.001$) and adopt soil conservation measures ($p < 0.001$) and adjust crop planning ($p < 0.001$). A positive correlation was observed between the degree of perceived threat and willingness to invest in sustainable practices ($r = 0.38$, $p < 0.001$).

3.3.5. *Regional differences in attitudes and willingness to implement sustainable practices*

Understanding regional differences in farmers' attitudes towards sustainable practices and water management measures requires considering the diverse agro-climatic conditions across Czech agricultural production areas. These conditions influence crop selection, productivity, and farmers' perspectives on sustainability and water management. Our analysis reveals significant regional variations in attitudes and willingness to implement sustainable practices, highlighting the need for tailored approaches to sustainable agriculture in different

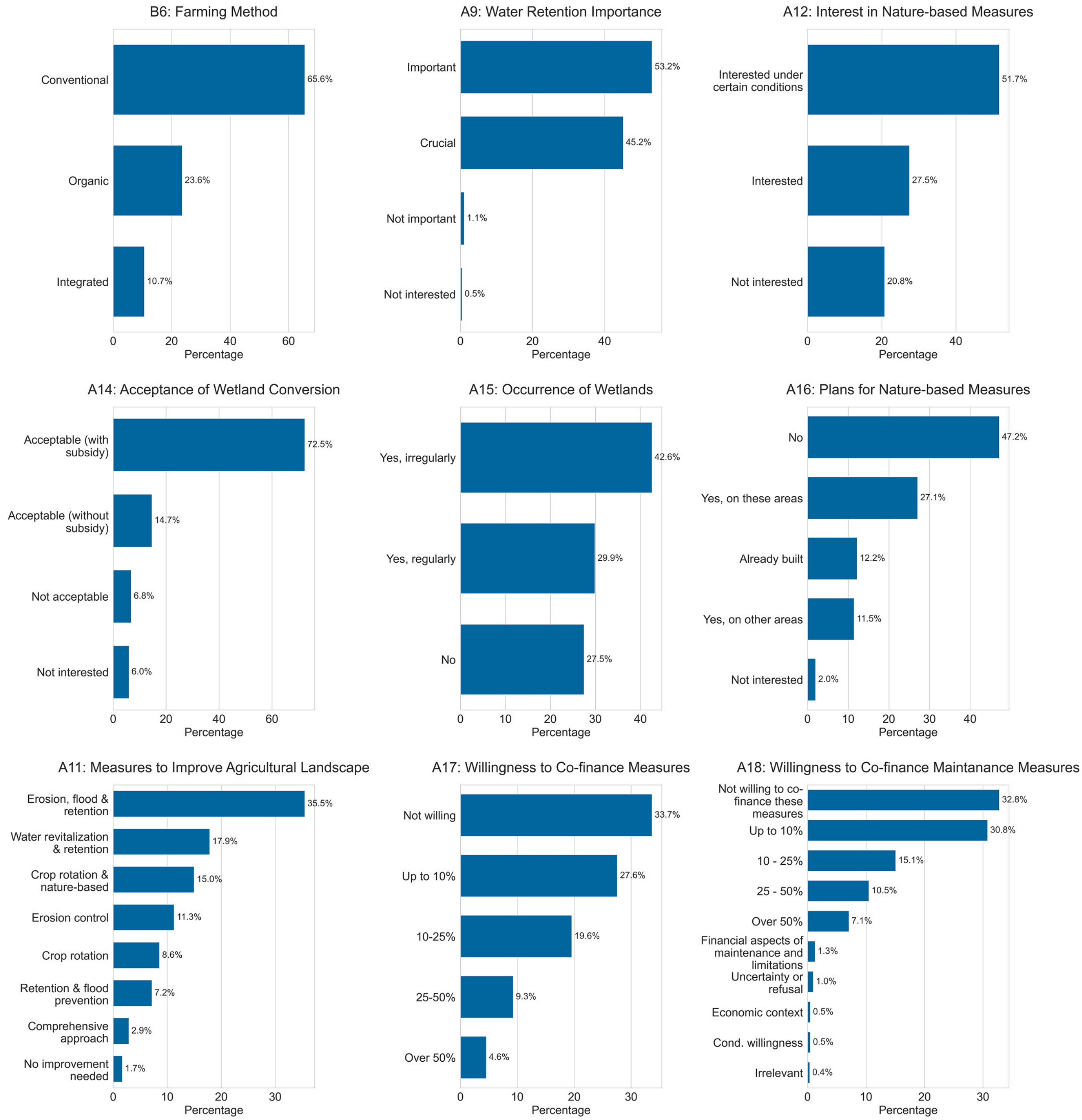

Fig. 7. Summary of survey results on farming practices, wetland acceptance, and willingness to co-finance sustainable agriculture initiatives.

areas.

Table 1 provides an overview of the main agro-climatic characteristics of agricultural production areas in the Czech Republic. The mountainous area has lower temperatures, higher precipitation, and a smaller soil water deficit. In contrast, the corn-growing area experiences the highest temperatures, lowest precipitation, and the largest soil water deficit, while the potato and sugar beet areas present intermediate conditions.

These agro-climatic differences are reflected in regional variations in farmers' attitudes towards sustainable practices and water management measures. Fig. 10 visualizes these regional differences in farmers' attitudes towards co-financing nature-based water retention measures, categorized by agricultural production regions. Farmers in mountainous areas demonstrate a greater willingness to implement water management measures than those in lowland areas ($p < 0.05$). This may be due to the higher precipitation and smaller soil water deficit in mountainous regions, increasing awareness of effective water management.

Conversely, farmers in the grapevine and maize growing areas show less willingness to invest in water retention measures ($p < 0.01$). This might seem counterintuitive given the area's larger soil water deficit and drier climate. This attitude could stem from a perception that water management measures are less effective or too costly in their conditions, or a stronger focus on irrigation. This highlights the complex relationship between environmental conditions and farmers' attitudes, suggesting that greater water scarcity does not automatically lead to greater support for all water management measures, especially retention-

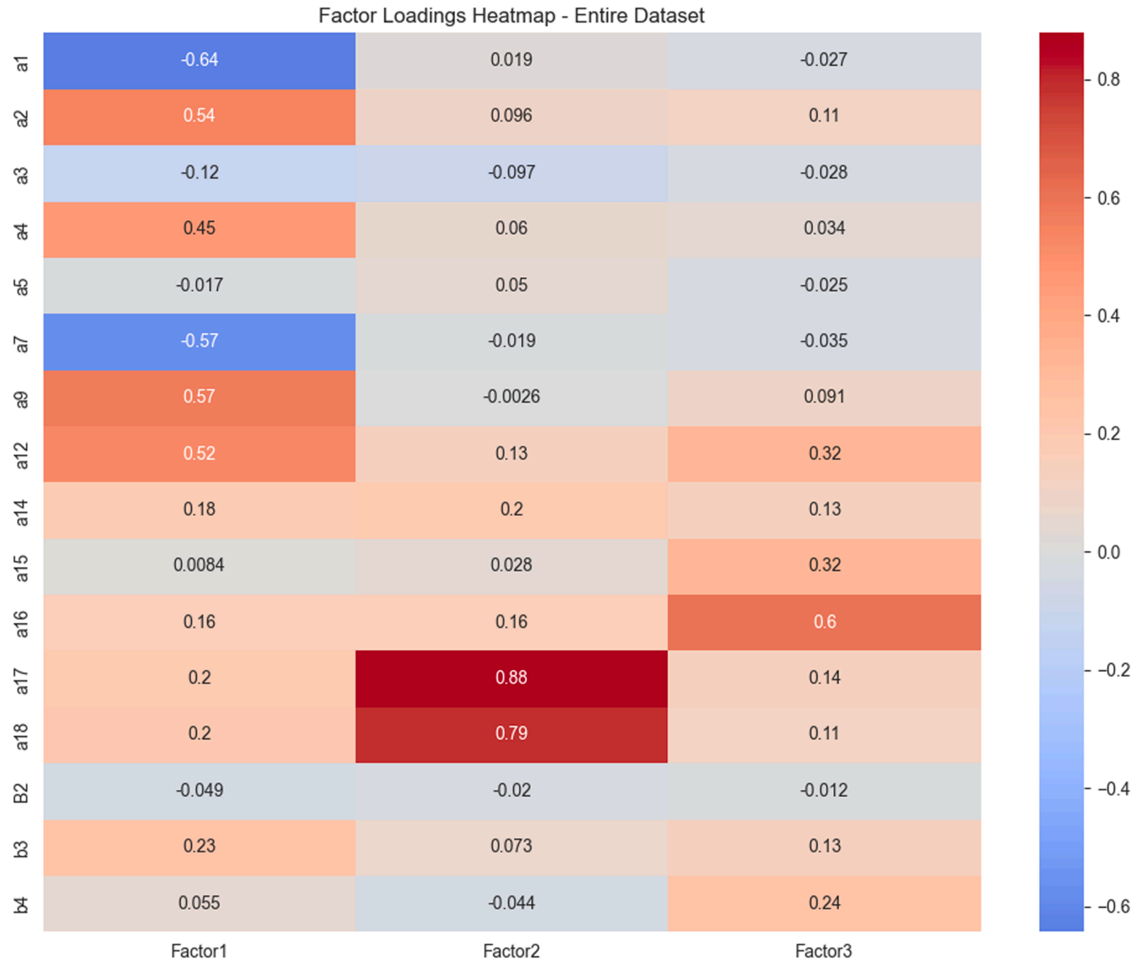

Fig. 8. Heatmap representing the results of factor analysis for key variables in the survey. The heatmap illustrates how strongly each survey question (variable) loads onto each of the identified attitudinal factors. The color intensity and direction in the heatmap indicate the strength and direction of these loadings (red for positive, blue for negative loadings).

focused ones rather than irrigation.

In cereal and potato-growing areas, with intermediate agro-climatic conditions (Table 1), we observed a higher occurrence of waterlogged areas and greater interest in retention measures. This aligns with the cereal and the potato-growing area's characteristics, having moderate precipitation and soil water deficit, potentially leading to waterlogged areas and increased awareness of the need for retention measures.

These regional differences in farmers' attitudes emphasize the need for a differentiated approach to implementing sustainable practices and water management measures across Czech agricultural production

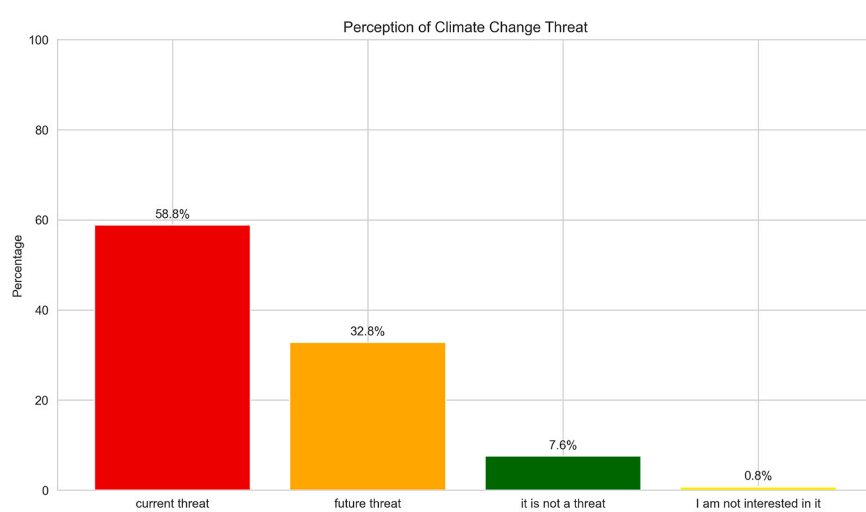

Fig. 9. Farmers' perceptions of climate change: awareness, concerns, and impacts on agricultural Practices.

Table 1
Agro-climatic characteristics of agricultural production areas (adapted from Trnka et al., 2021).

Agroclimatic zone	TS10 (°C)	KJJA (mm)	Climate conditions	Altitude (m a.s.l.)	Major crops grown
Grapevine production region	2950–3250	−210 to −140	> 10 °C, < 600 mm	< 140	grain maize, sunflower, soybean, grape wine, irrigated agriculture, vegetable, peaches, apricots
Grain maize production region	2800–3100	−180 to −100	9–10 °C, 450–600 mm	< 250	grain maize, sugar beet, grape wine, apples, peaches, apricots, high-quality wheat, malting barley
Sugar beet production region	2550–2950	−140 to −40	8–9 °C, 500–650 mm	250–350	sugar beet, grain maize, grape, high-quality wheat, malting barley, hops
Cereal and potato production region	2100–2700	−90 to −120	5–8.5 °C, 550–900 mm	300–650	cereals, rape, technical crops (growing sugar beet is not profitable)
Forage and grassland production region	< 2150	> −30	5–6 °C, > 700 mm	> 600	potatoes, rye, flax, hay, forage crops

TS10 - sum of active temperatures above 10 °C
KJJA - soil water deficit during the months June-August
m a.s.l. - meters above sea level

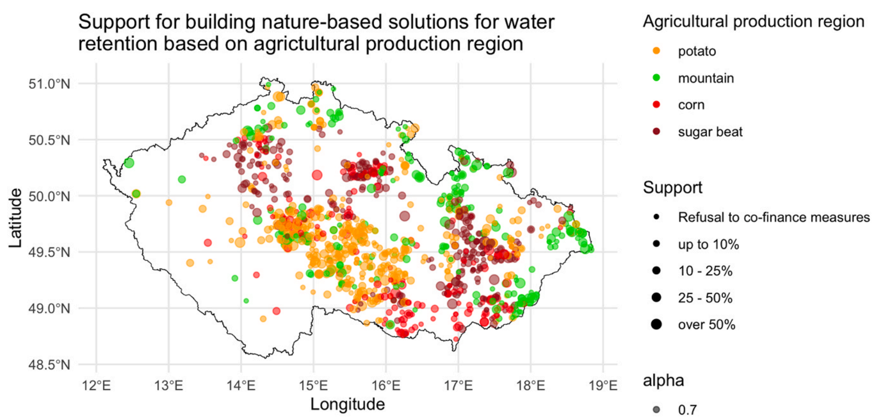

Fig. 10. Regional differences in attitudes towards co-financing nature-based water retention measures.

areas. While mountainous areas (forage and grassland production region) might benefit from strategies focused on efficient water use and managing waterlogged areas, the corn-growing area may require targeted education and support to overcome skepticism towards water retention measures, potentially focusing on benefits in drier conditions or efficient irrigation. In cereal and potato-growing areas, efforts could focus on developing and implementing measures for managing waterlogged areas and promoting suitable retention practices.

4. Discussion

4.1. Farmers' attitudes towards sustainable agriculture and water management

Methodological Complexity and Nuances of Farmer Attitudes: Our study reveals complex relationships influencing Czech farmers' attitudes, highlighting attitudinal multidimensionality. Discrepancies between factor analysis and detailed group analysis suggest multifaceted attitudes not easily reducible to a few factors. Complex interactions between attitude aspects manifest differently at individual question and factor levels, underscoring the importance of combining diverse analytical methods for understanding complex socio-economic phenomena in agriculture (Locatelli et al., 2015) and the need for holistic approaches to understanding farmer attitudes, mirroring landscape hydrological optimization (Petrovič et al., 2017).

Diversity of Attitudes and Influencing Factors: Czech farmers exhibit significant attitudinal diversity towards sustainable agriculture and water management, reflecting the complex agricultural sector. Organic farmers consistently demonstrate more positive environmental and water management attitudes than conventional farmers, with integrated farmers holding intermediate positions. This aligns with previous research (Bourceret et al., 2023) and suggests a gradual sustainability transition influenced by a combination of economic incentives, educational attainment, and deeply held personal values.

Farm size and education level emerge as key socio-economic factors shaping attitudes. In many international contexts, larger farms are often more willing to invest in environmental measures due to their greater financial capacity and potential for economies of scale (Amblard et al., 2023; Pavlis et al., 2016; Wittstock et al., 2022). However, our findings reveal a contrasting pattern in the Czech Republic, where larger farms demonstrate a weaker willingness to invest in water management measures ($r = -0.11$, $p < 0.05$). This divergence may stem from the historical and structural characteristics of Czech agriculture, including the legacy of collectivization, which has resulted in larger farms often being less flexible and less personally connected to the land. Conversely, smaller farms, which are often family-run, tend to exhibit stronger positive attitudes towards sustainable practices, likely due to their closer connection to the land and a greater sense of environmental stewardship (Huenchuleo et al., 2012; Pavlis et al., 2016).

Education also plays a crucial role, with higher education levels, particularly in agricultural fields, correlating with more positive attitudes towards sustainable agriculture and a greater willingness to adopt water management measures. This finding aligns with previous studies highlighting the importance of education in shaping environmental attitudes and behaviors (Amblard et al., 2023; Charatsari et al., 2011; Wittstock et al., 2022). Additionally, institutional and economic factors, such as access to extension services, credit, and training, have been shown to positively influence the adoption of conservation measures (Kumar et al., 2021). Similarly, studies on wetland restoration, such as Zhang et al. (2019) and Zhu et al. (2016), emphasize the importance of economic incentives and institutional support in encouraging farmers to participate in conservation initiatives. These findings align with broader research emphasizing the importance of location-specific and targeted policies to address regional differences in the adoption of soil and water conservation measures (Kumar et al., 2021; Zhang et al., 2019). The relatively weak correlation between farm size and willingness to invest in water management measures in our study underscores the need to consider a broader range of factors, including education, farming type, and regional specifics, when designing policies to promote sustainable agriculture.

Regional Differences and Water Management: Regional differences are also key determinants of farmer attitudes, particularly regarding water management. Mountainous region farmers, facing different agro-climatic conditions and water management challenges, are more willing to implement water management measures compared to lowland farmers (Mozny et al., 2023; Šarapatka and Štěrba, 1998). Wetland attitudes further highlight regional variations and farm-specific contexts. Smaller and crop-based farms, and farms in potato-growing areas with moderate precipitation, report both higher wetland occurrence and greater retention interest. Organic farmers and subsidy recipients also show greater wetland awareness and adoption of retention measures, potentially reflecting both environmental values and practical experience with subsidy programs that may support wetland management in problematic areas. Mountainous farms, characterized by higher precipitation, report more wetlands than lowland farms, underscoring the need for region-specific approaches to water management and wetland conservation.

4.2. Perception of climate change and policy implications

Czech farmers widely recognize climate change as a significant threat, yet high awareness doesn't strongly correlate with willingness to implement specific adaptation measures, highlighting an awareness-action gap. This discrepancy may stem from economic barriers, lack of knowledge, or measure suitability (Blackstock et al., 2010). Short-term vs. long-term planning and 'psychological distance' contribute to abstract threat perception (Spence et al., 2012; Weber, 2010). Emphasizing local and immediate climate change impacts and providing institutional and political support (Arbuckle et al., 2013) could encourage sustainable practices, as immediate threat perception increases adaptation willingness (Mase et al., 2017). Surprisingly, subsidy recipients and non-recipients perceive climate change similarly, suggesting current subsidies may not adequately address climate change concerns. Merely raising awareness is insufficient; a holistic policy approach is needed, including targeted support, education, communication, and supportive policy frameworks for climate change adaptation (Altieri et al., 2015; Smit and Wandel, 2006). These policy implications, along with key findings regarding farmer attitudes, are summarized visually in Fig. 11. Our study's key insights for agricultural practice and policy emphasize the need for differentiated agricultural policies tailored to diverse farmer attitudes, farm types, sizes, and education levels. Locally tailored approaches are crucial, considering regional agro-climatic conditions and specific needs regarding waterlogged areas and climate change perception. Holistic landscape management integrating production and ecological aspects is essential for waterlogged areas (Primdahl et al., 2013). Bridging the awareness-action gap requires targeted policies, support, communication, and financial incentives.

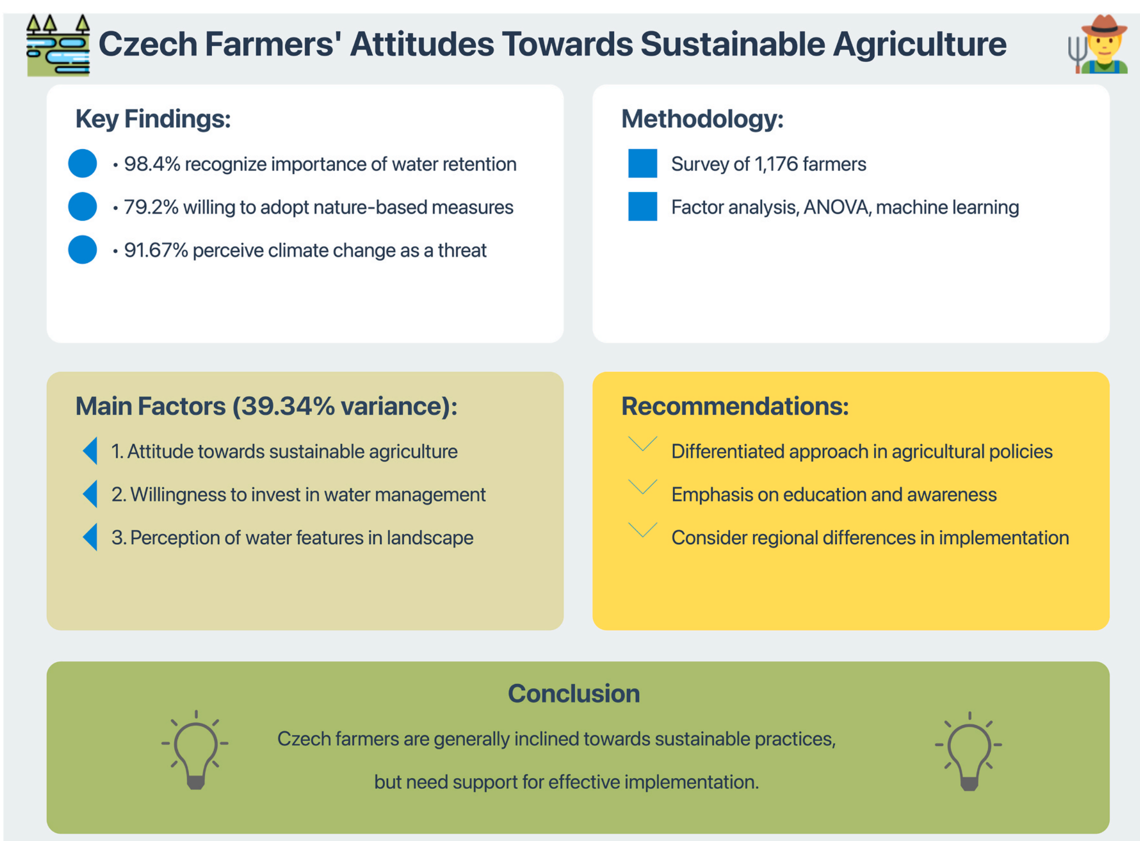

Fig. 11. Infographic summarizing the attitudes of Czech farmers towards sustainable agriculture. This visual representation highlights key findings, including the recognition of water retention's importance, willingness to adopt nature-based measures, and perceptions of climate change as a threat. It also outlines the methodology used in the study and provides recommendations for future agricultural policies.

4.3. Limitations and future research

While our study offers valuable insights into Czech farmers' attitudes, certain limitations warrant acknowledgment. Sample representativeness is a primary consideration, particularly given the voluntary nature of survey participation. Although distributed via the State Agricultural Intervention Fund (SZIF) to reach a broad spectrum of subsidy recipients (estimated at 99.0 % of eligible farmers), online questionnaires inherently carry a risk of self-selection bias. Farmers with greater interest in sustainable agriculture, water management, or digital engagement might have been more inclined to respond. To mitigate potential misunderstandings and enhance response validity, we pilot-tested the questionnaire with a smaller farmer group, focusing on question clarity and terminology comprehensibility.

Despite these measures, achieving complete representativeness in voluntary social science surveys remains challenging. However, we note that the proportional representation of key farmer groups, such as conventional and organic farms, broadly aligns with their national proportions, suggesting that the survey captured diverse perspectives relevant to our research questions.

Future research should address these limitations. Stratified random sampling could enhance generalizability across farm types and sizes. The cross-sectional design necessitates longitudinal studies to capture attitude dynamics over time. Furthermore, while the quantitative approach provided broad insights, qualitative methods would enrich understanding. In-depth interviews or focus groups could explore farmer motivations and barriers to sustainable practice adoption with greater nuance. Such qualitative research could complement our quantitative findings and provide a richer context for policy development.

Beyond methodological considerations, future research could also delve deeper into specific thematic areas. A detailed cost-benefit analysis of sustainable practices would inform policy effectiveness. Exploring the role of social networks and peer-to-peer learning could optimize information dissemination and innovation adoption. Analyzing the impact of specific policy measures and subsidy programs is crucial for targeted support. Further investigation into innovative technologies and adoption barriers, ecosystem service valuation, and the role of young farmers and agroforestry potential in the Czech context would also be valuable.

Addressing these limitations and pursuing these future research directions will contribute to a more comprehensive understanding of Czech farmer attitudes and inform more effective and targeted sustainable agriculture policies.

5. Conclusion

This study provides comprehensive analysis of Czech farmers' attitudes towards sustainable agriculture, environmental protection, and water management. Key findings reveal significant implications for agricultural policy and practice. A prominent insight is the significant attitudinal diversity among Czech farmers, highlighting the need for tailored policies that consider varying farm characteristics, regional contexts, and farmer education levels. Specifically, smaller, organic, and highly educated farmers generally demonstrate more positive attitudes towards sustainable practices, suggesting these groups may be more receptive to certain policy interventions, while larger, conventional farms may require different forms of support to overcome specific barriers. Regional differences also play a crucial role, necessitating locally tailored approaches to agricultural policy and environmental measures that account for specific agro-climatic conditions and regional needs, particularly regarding waterlogged areas and climate change perception.

Furthermore, the complex relationship of farmers to waterlogged areas underscores the need for holistic landscape management approaches that effectively integrate both agricultural production and ecological aspects, considering diverse farmer perspectives and promoting nature-based solutions. Bridging the gap between high climate change awareness and limited willingness to implement adaptation measures is a crucial policy challenge, requiring targeted strategies that go beyond mere awareness-raising and include improved communication about local climate change impacts, technical assistance, and financial incentives to motivate action. Therefore, effective climate change adaptation and sustainable agriculture in the Czech Republic necessitate a holistic and multi-faceted policy approach.

This comprehensive approach should encompass flexible and adaptable policies, strengthened educational programs and information campaigns, targeted support programs tailored to different farmer groups, integrated landscape management strategies, platforms for farmer knowledge sharing and peer-to-peer learning, and a gradual and flexible implementation process that ensures active farmer involvement to guarantee relevance and effectiveness in practice (Altieri et al., 2015; Bartkowski and Bartke, 2018; De Steven and Lowrance, 2011; Magnier et al., 2024; Papadimitriou et al., 2019; Rockström et al., 2017; Slavíková and Raška, 2019; Smit and Wandel, 2006). In conclusion, this study enhances understanding of Czech farmer attitudes and offers valuable insights for developing effective policies to facilitate the transition to sustainable agriculture and improved water management in the Czech agricultural landscape under climate change.

Authorship contributions

- Marek Bednář: Conceptualization, Methodology, Writing – Review & Editing, Data Curation, Visualization – Original Draft, Supervision.
- Renata Pavelková: Investigation, Formal Analysis, Resources, Writing – Review & Editing.
- Patrik Netopil: Investigation, Formal Analysis, Resources, Writing – Review & Editing.
- Bořivoj Šarapatka: Project Administration, Investigation, Formal Analysis, Resources, Writing – Review & Editing

"All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved."

CRediT authorship contribution statement

Bednář Marek: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Šarapatka Bořivoj:** Writing – review & editing, Resources, Project administration, Investigation, Formal analysis. **Netopil Patrik:** Writing – review & editing, Resources, Investigation, Formal analysis. **Pavelková Renata:** Writing – review & editing, Resources, Investigation, Formal analysis.

Ethical compliance statement

"This study was conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. The research did not involve any human or animal subjects, and no ethical approval was required."

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agwat.2025.109470.

Data availability

Data will be made available on request.

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