UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

Total word count: 10 426

The Vulnerability of Agriculture to Climate Change in the Świętokrzyskie Voivodeship

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April, 2024

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Abstract

Agriculture faces significant challenges due to climate change, including rising temperatures, shifting rainfall patterns, and increased frequency of extreme weather events. This study employed an interdisciplinary approach, combining semi-structured interviews, surveys, observations, soil analysis, and Normalised Difference Vegetation Index (NDVI) analysis, to evaluate the vulnerability of agriculture to climate change in the Świętokrzyskie Voivodeship. The findings revealed that a majority of farmers in the region experienced climate change and its detrimental impact on their agricultural activities, with drought emerging as the primary concern, followed by flooding. The findings from NDVI analysis indicated that the majority of vegetation is growing below the threshold considered healthy. Additionally, it highlighted how the impact of droughts on vegetation health poses a direct risk to agricultural activities in the region. While soil analysis did not show alarming levels for most parameters evaluated, they exhibited suboptimal characteristics. Potentially in response to the changing climatic conditions, farmers predominantly resorted to crop rotation and diversification as adaptation strategies. The study also uncovered concerning trends within the region, such as a lack of subsidies for farm management, financial struggles and a declining attractiveness in farming. These insights shed light on the vulnerability of agriculture in the Świętokrzyskie Voivodeship amidst climate change, highlighting the pressing need for interventions and policies to enhance the resilience of agricultural systems.

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Table of abbreviations

ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	Fifth generation ECMWF Reanalysis
LUCAS	Land Use and Coverage Area frame Survey
NDVI	Normalised Difference Vegetation Index
SOC	Soil Organic Carbon
WHC	Water Holding Capacity

Acknowledgements

Thank you to all the participants who offered their assistance, and without whom we would not have been able to complete this research.

We would like to express our gratitude to the Polish translators helping us throughout this project, to our supervisors, for their valuable support and encouragement, and to the University of Warsaw European Centre for Geological Education for their hospitality.

Dina, Genesis, Kondi, Alonso, Elia.

Introduction

Europe is witnessing a discernible shift in weather patterns, largely attributed to human-induced climate change, as highlighted in the IPCC report (2023). Poland stands out as a relevant case within this narrative, exhibiting clear signs of altered atmospheric circulation patterns and climate change, notably evidenced by the rising average temperatures and precipitation variations (Falarz, 2021). In this context, during this study, climate change encompassed both climate variability and extreme weather events. Since the mid-20th century, Poland has experienced a notable temperature increase exceeding 2°C, surpassing the global average rise over the last decade by nearly 200% (IEA, 2022; Meteo IMGW-PIB, 2023). In the eastern region particularly, high temperatures and extremely hot days have increased by 400% since 1991, underscoring a pronounced regional climate change (UNFCCC, 2022). Moreover, increased occurrence and intensity of extreme excess and deficit of precipitation persists. The South-eastern region of Poland, where extreme weather events are the most frequent and intense, is especially vulnerable to extreme phenomena such as heatwaves, floods, droughts, strong storms or hurricanes (Jacek, 2017). Overall, climate projections anticipate a continued rise in precipitation intensity and extreme weather events across the country in the coming decades (IEA, 2022).

Agriculture is one of the sectors most vulnerable to climate change (IPCC, 2014); adversely affecting crop growth, soil moisture equilibrium, water security, biodiversity, and soil erosion ultimately leading to crop failure and agricultural insecurities (Kundzewicz *et al.*, 2018; UNCFFF, 2022). The impact of climate change in Poland is particularly noteworthy considering the significant economic and social importance of this sector for the country. Poland exhibits the highest number of inhabitants professionally active in agriculture in Europe (Kundzewicz *et al,* 2018). Accounting for over 2.2% of the Polish GDP (Petrick *et al.,* 2004), 52% of the country's territory and 1.4 million farms are dedicated to this economy (European Commission, 2024). In fact, agriculture has witnessed significant growth in the past decade, bolstered by an institutional framework established during Poland's EU accession in 2004 (Wąs *et al.*, 2020). However, the cumulative negative effects of climate change heightens the vulnerability of agriculture, particularly in this Southern region of Poland.

Moving forward, the changing environmental conditions bear significant implications for the future of Poland. With climate change-related hazards potentially affecting up to 15 million Polish citizens, it appears crucial to conduct research on the resilience and vulnerability of Poland's agricultural system (UNFCCC, 2022). Such insights are essential to the formulation of a strategic plan to mitigate potential harms, especially with regards to Poland's commitment to climate change adaptation, outlined in their National Strategy for Adaptation to Climate Change (NAS, 2020).

Drawing on the conceptual framework of vulnerability, this paper seeks to investigate the threat of climate change in the Voivodeship of Świętokrzyskie to gain a better understanding of the susceptibility of agriculture and the development of adaptation strategies. It is anticipated that farmers in the region are facing challenges across various sectors of agriculture, making them susceptible to the impacts of climate change and overall affecting the agricultural system as a whole. The focus is placed on the Świętokrzyskie voivodeship due to its pronounced exposure to climate change and the limited research conducted in this region. The research question of this paper inquires:

How vulnerable is the agriculture system in the Świętokrzyskie Voivodeship to the impacts of climate change?

To investigate this research question, the following sub-questions and hypotheses are raised:

1. Is climate change perceived and experienced in the agricultural sector?
   Hypothesis 1.1: There is a general perception that environmental conditions have changed over the years.
   Hypothesis 1.2: Farmers perceive climate change as a future challenge and agricultural risk.
2. How has climate change affected agricultural productivity?
   Hypothesis 2.1: Farmers perceive a decrease in productivity due to climate change.
   Hypothesis 2.2: Vegetation health has declined across time.
   Hypothesis 2.3: Vegetation health declined as a response to droughts.
   Hypothesis 2.4: Agricultural soil quality has declined.
   Hypothesis 2.5: Agricultural soil is not adaptable to the new climate conditions.
3. Has agriculture adapted to climate change in the Świętokrzyskie voivodeship?
   Hypothesis 3.1: New agricultural techniques have been introduced by farmers in response to climate change.
   Hypothesis 3.2: Farmers receive increased financial support to implement adaptation measures.

Theoretical Framework: Vulnerability Assessment

In recent years, there has been a notable increase in vulnerability assessments within the scientific literature, particularly focusing on evaluating the vulnerability of sectors like agriculture to climate change (Baca *et al,* 2014; Fritzsche *et al,* 2014; Jurgilevich *et al,* 2017). Vulnerability denotes the susceptibility of a natural ecosystem or socio-economic system to the impacts of climate change (Fellmann, 2012). According to the Intergovernmental Panel on Climate Change (IPCC, 2007:883), vulnerability corresponds to 'the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and -extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity'. Exposure is defined as the frequency, intensity, and duration of perturbations affecting agricultural systems; sensitivity, as the system's susceptibility to these disturbances; and adaptive capacity, as the capacity to implement effective adaptation strategies to cope with environmental changes (Figure 1).

In order to reduce agriculture's vulnerability to climate change, adaptation is a crucial element of any policy response to climate change in agriculture (Moriondo *et al.*, 2010). Adaptation encompasses diverse measures and policies aimed at enhancing communities' resilience to changing weather conditions, which is crucial for sectors like agriculture, susceptible to temperature shifts, rainfall variability, and extreme weather events. Agricultural adaptation is often prompted by factors such as temperature fluctuations, rainfall variability, and extreme weather events, all of which can adversely affect crop yield (Grigorieva *et al.,* 2023). Iglesias *et al.* (2012) delineate two levels of agricultural adaptation: farm-based measures driven by farmers' interests and policy-driven adaptation entailing governmental intervention. Additionally effective adaptation strategies are contingent upon the availability and efficient utilisation of resources, and may be facilitated or hindered by external factors (Jamshidi, 2019).

Vulnerability in agriculture research is a multifaceted concept that not only reflects the degree of susceptibility to climate change but also shapes the design and implementation of adaptation strategies. Vulnerability assessments serve as a crucial foundation for policy responses and are therefore essential for fostering resilience in agricultural systems (Berry *et al,* 2006). This study aims to assess the resilience of the agricultural system in the Świętokrzyskie voivodeship by examining its vulnerability to climate change. The research utilises the components of exposure, sensitivity and adaptive capacity to evaluate the vulnerability of farmers and agricultural systems, an approach aligning with previous studies (Jamshidi *et al.,* 2019; Loi *et al.,* 2022; Parker *et al.,* 2019). A range of context specific indicators were developed and selected to direct the vulnerability assessment (Dietz, 2015) (Figure 1).

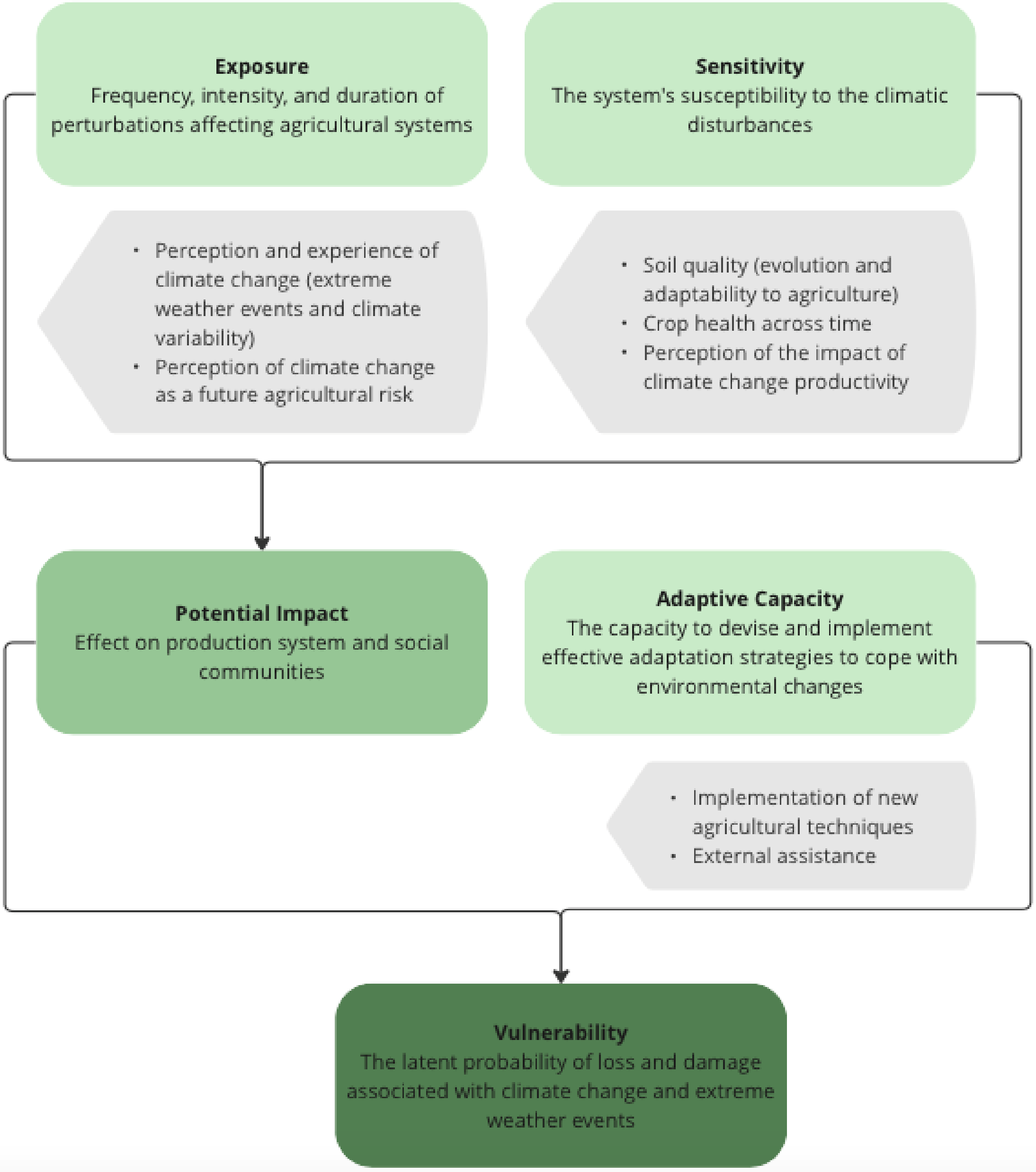


Figure 1. Vulnerability Framework: Components and Indicators for Assessing the Vulnerability of Agriculture in the Świętokrzyskie Voivodeship

Contextual Background: Świętokrzyskie Voivodeship

Approximately 60% of Poland's territory is dedicated to agricultural activities, underscoring the significance of soil quality in its agricultural productivity (European Commission, n.d.). Poland struggles with poor soil quality and inadequate infrastructure, obstructing agricultural output, with 62.5% of agricultural land facing natural constraints (ibid). Intensive agricultural practices further place the ecosystem under immense pressure, resulting in environmental challenges such as erosion, low organic matter, and nitrate pollution (ibid). The composition of Poland's soil includes over 50% alluvial clay, 26% sandy soil, and other types of soil, with just 1% being the fertile soil, chernozem, primarily located in the Świętokrzyskie voivodeship (Koncewi-Baran & Świtek, 2021).

The Świętokrzyskie voivodeship is located in the South-Eastern part of Poland (Figure 2). Over the last two decades the voivodeship has experienced a simultaneous reduction of 2.53% in farmland and farm numbers, and a trending increase in farm size at an individual level (Musial *et al.*, 2020; Wilczek, 2021). As a result, agricultural production is primarily conducted on farms with an average size exceeding 7 hectares (Statistical Office in Kielce, 2019). This shift can be attributed to the social and economic changes that Poland underwent upon joining the European Union in 2004 (Musial *et al.,* 2020). Despite the decrease in farmland, the voivodeship remains predominantly agricultural, boasting higher yields compared to other voivodeships (ARIMR, 2024). The Świętokrzyskie voivodeship mirrors national trends in terms of produce, with cereals such as wheat, oats, rye, and barley dominating production. Other crops feature sugar beets, potatoes, and turnip rape (Statistical Office in Kielce, 2022).

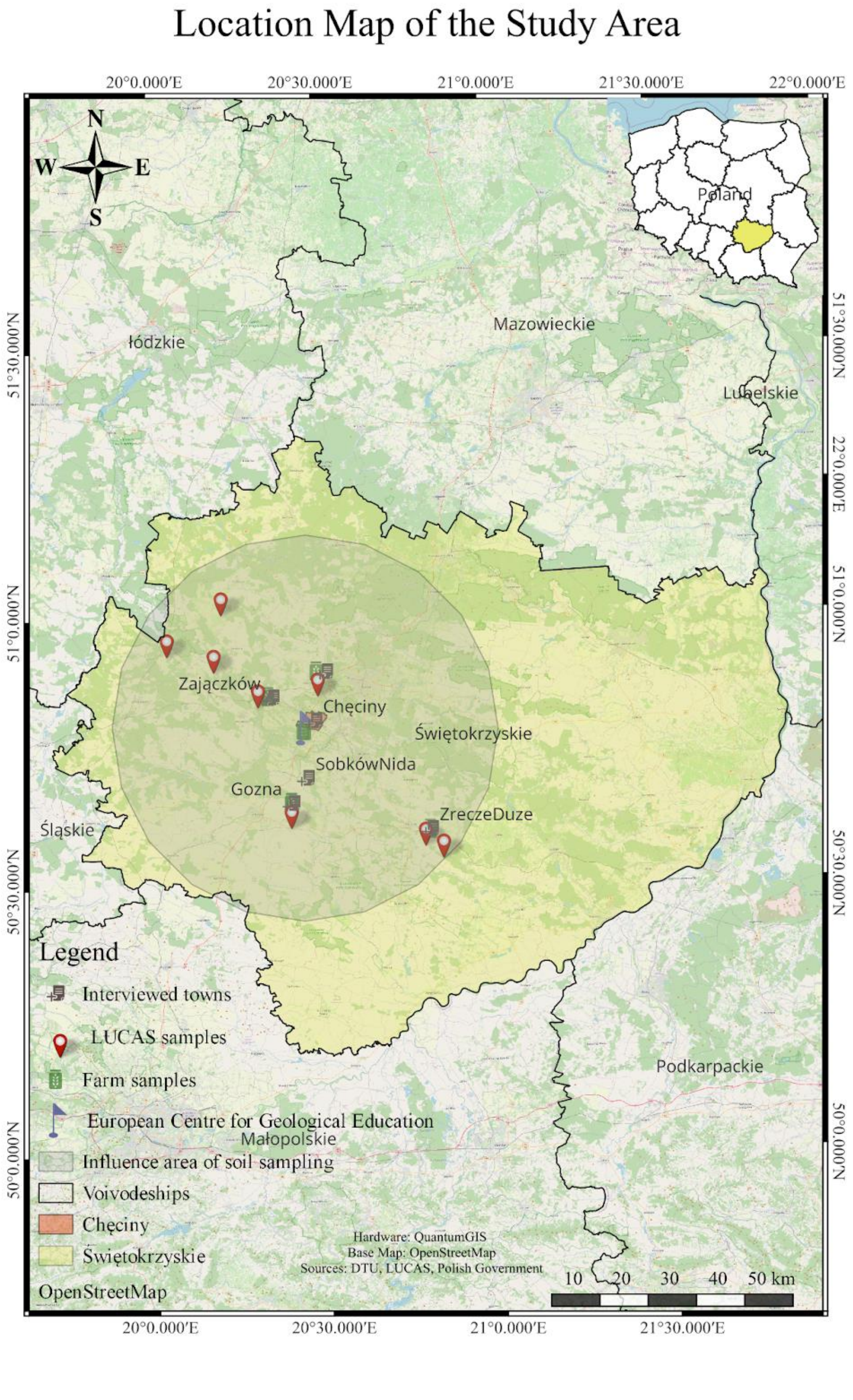


Figure 2. Location Map of the Study Area

Research Methods

This section provides an overview of the methodologies utilised in this study, along with a discussion of the advantages and limitations associated with each method. Taking into account the diverse backgrounds within the group as well as the interdisciplinary nature of the Practising Interdisciplinary Fieldwork course, a mixed-method approach combining social and natural sciences was adopted. This approach allowed for the collection of both quantitative and qualitative data, enabling triangulation of findings. The study employed three social science methods: surveys, semi-structured interviews, and observation, alongside two natural science methods: soil analysis and Normalised Difference Vegetation Index (NDVI).

Social Science Research Methods

Surveys

Twenty-five surveys were conducted to explore farmers' perceptions of environmental conditions (Elhami and Khoshnevisan, 2022). The choice of methods stemmed from consideration of potential language barriers and desire to render the data collection method as straightforward as possible for the translator.

Due to limited resources and time constraints, convenience sampling was employed to select the participants of the surveys, inquiring farmers directly on their farms in the area of interest. A total of 25 farmers were surveyed within the Świętokrzyskie voivodeship (Figure 2). To encourage participation, farmers received some incentives, including the proposition of a report detailing their soil properties (see Appendix 5) and Danish candies in hand-sewn pockets as a token of appreciation. Locating farmers at home or on the fields posed one of the most important challenges during the research process.

The surveys gathered and explored the following information: demographic data; perceptions of changing environmental conditions (weather variability and extreme events); changes in agricultural behaviour (crop calendar, harvest, yield productivity, harvest, and soil quality) and the development of adaptation strategies in response to climate change dynamics. The survey guide was established taking inspiration from the Bayer Farmer Voice Report 2023 (see Appendix 2).

Before surveys, participants were briefed on the research's nature and their rights and asked for informed consent for their voluntary participation (Curtis and Curtis, 2003:181). The specific research question was withheld from participants, who were given the broad topic of the research avoiding the use of the terminology 'climate change'. This was due to the belief that Polish farmers might deny the existence of climate change. Instead, using the terms ‘weather change’ was thought to prevent response distortion and safeguard the validity of findings, especially when considering the potentially controversial nature of the study (De Vaus, 2002:60). A previous study from Italy further identified that farmers aligned better with the phrase weather variabilities rather than climate changes (Nguyen *et al.,* 2016). Participation terms assured anonymity, confidentiality, and privacy.

Survey results underwent a statistical quantitative analysis using the software R (version 4.3.2). A cross-tabulation analysis was used to evaluate the relationship between climate change perception and the adoption of new farming techniques by surveyed farmers as well as between climate change impact on yield and the adoption of new farming techniques.

Semi-structured Interviews

Twelve semi-structured interviews were conducted with key informants from a local bank, the Agricultural Advice Center and the Mayor of one of the voivodeship’s towns, as well as with agro-industries.

The interviews with specialised key informants explored topics such as existing financial support to farmers for adapting to the changing climate; agricultural trends in the area; and agricultural difficulties related to climate change. Semi-structured interviews with agro-industry informants further gathered information on industry sales of the industries in the voivodeship, and perceptions of adaptation capacity of their technology to climate change.

Purposeful sampling, selecting individuals experienced with the phenomenon of interest, was used to facilitate recruitment information-rich cases, such as the mayor, bank informants and Agricultural Centre Advisors (Cresswell and Plano, 2011; Patton, 2002). This non-probabilistic controlled approach allowed for in-depth exploration of the complex factors that participate in shaping changing agricultural practices (Lunn, 2018). Agri-industry interviewees were selected using a convenience sampling method based on the industries present at the Agrotech Agricultural Trade Fair of Kielce.

Semi-structured interview results underwent a thematic qualitative analysis, using the software NVivo (version 14.23.3(61)). Thematic analysis was chosen to gain insight into participants' perceptions, practices and motivations (Terry *et al.,* 2017). Recurring patterns of behaviour and attitudes were identified and analysed by following Braun and Clarke's (2006) six-step process of analysis, including familiarisation with the data, generation of initial codes, search, review, definition and exploration of themes.

The language barrier was the main challenge faced during the field-work. Semi-structured interviews and surveys were developed by the research group but conducted and translated by a translator to ensure accurate communication of the research objectives to the participants. Possible loss of information during translation and misunderstandings from translators or interviewees was a key consideration. To mitigate these risks, the translator was thoroughly briefed on the report's objectives and the data being investigated. Their background in geology and extensive experience in conducting interviews in the specific location of Poland proved to be advantageous. Additionally, highly structured and straightforward surveys were used as one of the primary research methods to overcome language-related challenges.

Observation Methods

Complementary observation methods of farms in the voivodeship and technology used on the fields allowed to gather information on the impacts of climate change and adaptation pursued by farmers (see Appendix 4). Methodological triangulation was used to verify the validity of the results.

Soil Analysis

The research incorporated soil analysis as an essential element to explore the resilience of agriculture to climate change. Soil samples taken during the fieldwork in 2024 were compared with past soil analysis data from 2015 and 2018, from the European soil database 'LUCAS' (ESDAC 2015, ESDAC 2018). The sampling was conducted on 8 different locations across the Świętokrzyskie voivodeship, with one cluster collected at each location based on the coordinates of previous soil samples (Figure 2). At each cluster, three soil core samples were extracted. While opting for three independent replicates for each coordinate from the LUCAS database would have enhanced the representativeness of the analysis, logistical constraints, particularly limited space during soil transportation back to the Copenhagen laboratory, dictated replicate size. In addition, the selection of soil samples was constrained by the LUCAS coordinates, which allowed only one cluster to be investigated.

Samples were air dried before undergoing laboratory analysis, focusing on parameters of organic carbon and pH. A statistical analysis; comprising of a Kruskal-Wallis test, followed by pairwise comparisons using Wilcoxon rank sum exact test were conducted in R (version 2023.06.1) to compare the soil parameters over time.

To assess the adaptability of soil to evolving climate conditions, an additional 5 soil samples were collected from the fields of farmers surveyed (Figure 2). For each field, 3 clusters were randomly selected, where 3 replicates of soil core samples were taken and combined as a homogeneous composite sample. Samples were air dried before undergoing analysis in the laboratory of soil texture, water holding capacity (WHC), total Carbon (C), total Nitrogen (N) and pH. Descriptive statistics were used to analyse general characteristics of the soil and its adaptability.

Soil texture

After adding water to the samples until uniformly moistened, they were characterised in terms of texture using the finger method as described by Rowell (2014).

Water Holding Capacity

Five plastic tubes were filled with 5-7 cm soil from each farm. The tubes stayed in a water bath for 24 hours and were transferred to a tray with sand until constant weight was achieved. Hereafter they were placed in a beaker and the wet-weight was measured. The mass was dried at 105°C, cooled in a desiccator and reweighted (Müller-Stöver, 2024).

Total N and C

A tablespoon of all the soil samples were dried in the oven on 100 degree celsius overnight. Subsequently, the soil was crushed to a fine powder using a mortar. For each sample, 100 mg of soil was measured and transferred into a tin weighing capsule together with 100 mg of Tungsten (VI) oxide. The capsules were inserted into a 48-well plate to perform the Isotope-Elemental Analysis.

pH

The protocol for soil pH determination details in the standard norm ISO 10390:2021 was used (International Organization for Standardization, 2021). This is in accordance with the methodology used in the LUCAS database.

Organic C

The methodology for measuring total C was used to approximate organic Carbon (C) content in the samples.

In the laboratory analysis of soil samples, several challenges were encountered, primarily stemming from the unavailability of materials and methods required for certain measurements. One notable obstacle was the absence of the specific methodology outlined in the LUCAS database (ISO 10694:1995) for measuring organic C. To address this limitation, an alternative method for measuring total C was explored, with the assumption that it provided a reasonable approximation of the amount of organic C in the soil samples. Additionally, due to material constraints, only one of the three samples collected from each farm was used for measuring WHC, in order to accommodate the available resources.

Normalised Difference Vegetation Index (NDVI)

To assess vegetation health and detect changes over time in Świętokrzyskie voivodeship, NDVI analysis was conducted using QuantumGIS (version 3.28.15). NDVI has demonstrated effectiveness in accurately describing vegetation density and conditions (Baldi *et al.,* 2008; cited in Ahmed, 2016). Imagery from Landsat, obtained from USGS, was compared across the years 2013 to 2023. A three-year interval was chosen, starting from 2013 until 2022, with the addition of 2023, based on the last available June images from USGS. The selection of June as the focal month stems from its relevance to crop vegetation, representing a period after growth but before harvest.

Additionally, an analysis of the years 2018 and 2020 was conducted in order to assess the impacts of drought on vegetation and crop health in Świętokrzyskie Voivodeship. Despite the initial plan to use imagery from June, which corresponded to the periods of reported droughts, extensive cloud cover rendered suitable images unavailable. In consequence, the analysis was conducted using imagery from May (including one image from April) and August to observe the impacts of the droughts on vegetation's health.
Vegetation changes were calculated using the NDVI formula: (NIR-RED)/(NIR+RED) (Gashaw et al., 2014, as cited in Ahmed, 2016). NIR represents the near-infrared band and RED the red response (Ahmed, 2016). For Landsat data, Band 5 represents the NIR band and Band 4 the RED band. The images obtained for each specified year were processed through QGIS to mitigate the presence of excessive cloud cover. The processing involved cutting and merging the images to enhance precision in running NDVI analysis. For the NDVI analysis, many of the selected monthly images contained significant cloud cover. Hence, it was essential to gather images from different dates within the same month, allowing for the removal of cloud-covered sections through cutting and subsequent merging. Although complete avoidance of clouds was not feasible, this approach significantly minimised their presence in the analysed images. The process followed for NDVI analysis can be found in Appendix 3.

The index values span from -0.1 to 1, with active vegetation typically ranging from 0.1 to 0.7 (Ahmid, 2016). A NDVI classification pixel range was established by Atun *et al*. (2020) where values below 0 represents water, 0 represents bare soil, 0 to 0.3 is sparse vegetation or unhealthy vegetation (NASA, 2000), 0.3 to 0.5 is moderate vegetation or stressed vegetation (Ahmid, 2016), and over 0.5

represents dense vegetation or healthy vegetation (Ibid). To visualise the values effectively, the images were assigned a pseudo colour monoband from red to green (RdYlGn), where red (-0.1 to 0) represents no-vegetation, yellow (0 to 0.3) represents unhealthy vegetation, light green (0.3 to 0.5) is stressed vegetation, and green (0.5 to <) is healthy vegetation. Using these images, maps were created and frequency distribution graphs were obtained from QGIS to examine the vegetation health changes over the years and during droughts. The frequency distribution graphs provided by QGIS lacked uniformity in their X and Y axis values and bin size, hindering precise interpretations (Amgen Foundation, 2021). Therefore, Photoshop was used to edit each graph in order to provide the consistent values and bin size for accurate analysis and interpretation.

Results

In this section, the socio-economic profiles of the surveyed farmers and their farms are first introduced to provide contextual background to the data. Subsequently, overarching challenges affecting agriculture are discussed, structured around the four primary challenges identified through surveys and interviews with farmers and key informants. Lastly, emphasising the central theme of adaptation in this report, the final section of the results explores the adaptation strategies employed in response to climate change.

1. Socio-economic characteristics of the sample of farmers

The following socio-economic characteristics for the 25 farmers surveyed (n=25) were gathered: information on gender, years of farming experience, age, education level, farming type, farm size, agriculture contribution to household income, and the types of crops grown in the last years (Figure 3 and 4).

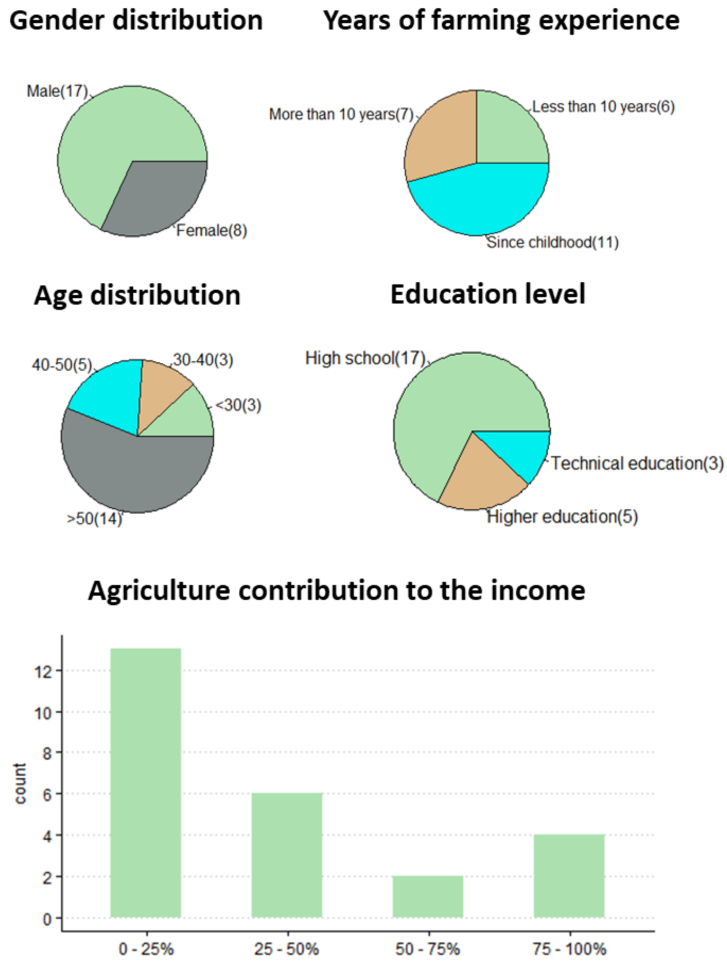


Figure 3. Key socio-economic characteristics of the respondents.

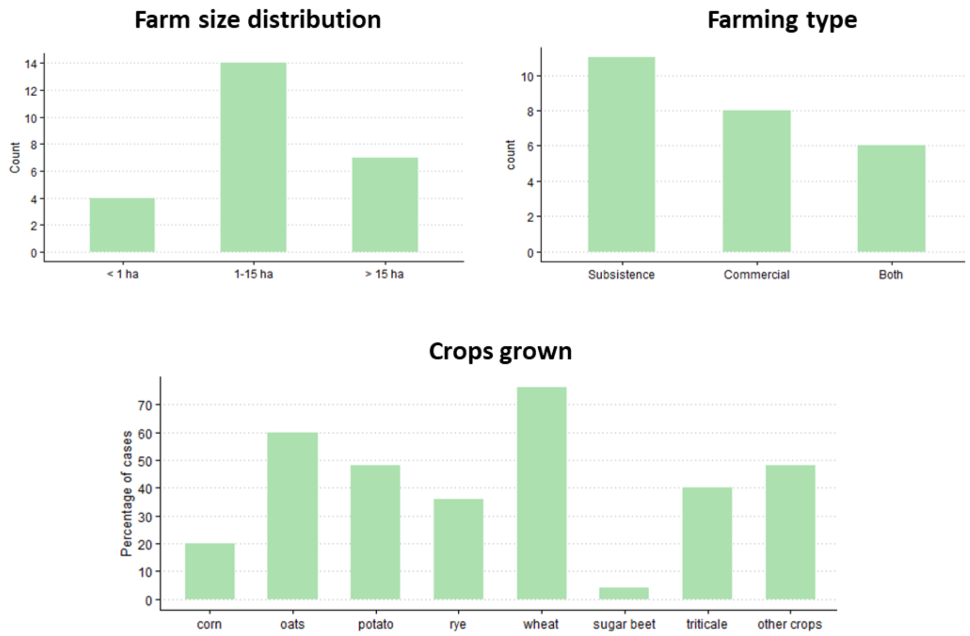


Figure 4. Key farming characteristics

The demographic profile of participants reveals a predominance of males, and nearly half of them engaged in farming since childhood. Over half of the participants were aged 50 and above, and had a high school degree as the highest completed education (Figure 3). Farm size primarily ranged from 1-15 hectares, with the majority of participants engaged in farming for subsistence purposes (Figure 4) and with agriculture contributing 0 to 25% to their income (Figure 3). Regarding crop cultivation, the most commonly grown crops, in descending order, were wheat, oats, potatoes, triticale, rye, corn, and sugar beets. Additionally, half of participants also cultivated crops that were not listed as options (Figure 4).

Challenges for Agricultural Activities

As anticipated, the interview and survey process indicated a common experience of struggle and challenges regarding agricultural activities. The following four interlinked challenges were prominently discussed.

2.1 Low soil quality

One major issue highlighted was the low quality of soil. Farmers and agricultural experts described the soil in the region as ‘weak’, ‘one of the worst’ and ‘overused’. This mentioned deficiency in soil quality had significant consequences on farmer’s agricultural outputs. Many of them noticed ‘lower harvests’ and ‘weaker crops’; directly impacting their livelihoods to the extent that they found it ‘hard to make a profit from soil'. Results from the survey revealed that 15 out of 25 participants noticed a change in the quality of their agricultural soil. Reduced soil fertility, acidity and water retention were their biggest concerns. Adverse weather conditions and the impacts of climate change, such as 'droughts', 'lack of water', and 'warmer' temperatures, as well as the high cost of fertilisers or the lack of livestock to provide organic fertilisers were cited as contributors to the declining quality of their soil. As a result, a considerable number of farmers were compelled to shift towards careers in industry, and abandon their farming practices.

The experimental analysis of soil quality revealed a statistical significant difference in the pH of sampled plots across time: a slight increase in the LUCAS database values, from 2015 and 2018 was reported. In contrast, the statistical test indicated no significant change in organic C (Table 1). The samples taken from the informants' farms allowed a broader description of the soils' characteristics and adaptability (Table 2).

Table 1. pH and C content values for the analysed soil samples across time

	pH			Organic C (g/kg)		
Sample	2015	2018	2024	2015	2018	2024
L1	5.9	5.0	5.6	22.1	24.2	14.1
L2	4.8	4.7	5.5	12.5	14	12.3
L3	4.4	4.4	5.6	19.1	24.2	26.5
L4	4.9	5.4	5.6	4.3	5.3	7.6
L5	5.2	5.2	6.5	4.9	6	10
L6	4.3	5.2	5.6	9.3	13.9	10.9
L7	4.9	5.1	6.7	9.1	16.2	22.6
L8	5.6	5.1	6.2	23.8	21.5	42
Range	4.8 - 5.9 (a)	4.4 - 5.4 (a)	5.5 - 6.7 (b)	4.3 - 23.8	5.3 - 24.2	7.6 - 26.5

Note: Letters indicate statistically significant differences ($P \leq 0.05$). Data from 2015 and 2018 taken from LUCAS database.

Table 2. Soil properties of farms

Farm	Texture	WHC (%)	C (g/kg)	N (g/kg)	C/N	pH
1	Silty clay loam	31.3	11.1	1.4	12/1	6.5
2	Loamy sand	33.9	19.4	1.8	11/1	7.6
5	Sandy loam	27.7	14.8	1.3	11/1	6.3
8	Loam	21.3	8.0	UDL	N/A	8.1
19	Clay loam	22.1	8.9	UDL	N/A	7.0
Range	-	21.3 -33.9	8.0-19.4	1.3-1.8	-	6.3-8.1

Note: Shows the results of texture, water holding capacity (WHC), organic carbon (C%), total nitrogen (N%), C/N ratio, and pH from the 5 farms (1,2,5,8, and 19) where soil samples were taken from. UDL is the abbreviation of “under detective limit” and N/A is the abbreviation of “not available”.

With the exception of Farm 2, which features sandy soil, all farms have loamy soil ranging from sandy loam to clay loam. In terms of water holding capacity, Farms 2, 1, 5, 19 and 8 rank from highest to lowest. Regarding carbon content, Farm 2 displayed the highest amount (19.4 g/kg) and Farm 8 displayed the lowest (8.0 g/kg). For total nitrogen, Farms 8 and 19 registered values below detectable level, while Farms 1, 2, and 5 showed relatively similar amounts of nitrogen. The results of organic carbon and total nitrogen yields a C/N ratio of 12/1 for Farm 1, and 11/1 for Farms 2 and 5. For Farms 8 and 19 the ratio could not be calculated. Regarding pH values, Farms 1 and 5 demonstrated the lowest pH values, whereas farm 8 exhibited the most basic value at 8.1. Farm 2 and 19 fell in between in terms of pH values (Table 2).

2.2 Lack of Financial Sustainability of Farming

Financial struggles, particularly concerning the sustainability of farming, were dominant in farmer’s discourses. Experts from the Agricultural Centre highlighted the ‘unstable’ commercial conditions of farming ‘due to the lack of profitability of sales’. This was echoed by the bank informants, who noted a drastic reduction in farm loans over the past decade, with percentages of loans given to farmers going down from 15% to approximately 8%. These numbers translate to the increasing difficulty for farmers to qualify for loans due to financial constraints. Agri-industry stakeholders interviewed also described some challenges with decreasing or stagnating sales in their company due to the 'price sensitivity' of this region of Poland (Agro-Industry Interviewee 5).

Description of the overall economic landscape by the informers highlighted declining crop prices resulting from low import restrictions from Ukraine and restricted exports to Russia, coupled with significant increases in fuel and fertiliser costs. This is due, in part, to farming activities no longer being sustainable financially. The experts from the Agricultural Advice Centre approximated a 50% reduction in usable agricultural land in the Voivodeship over the past 20 years.

Text Box: Case Studies: Testimonials from Farmers on Financial Instability

One farmer described struggling with a surplus of wheat as buyers wait for prices to drop lower before purchasing the products.

Another farmer was employed by a large food industry; tasked with receiving cows, feeding them until maturity, and then returning them to the industry. His primary concern lied in the risk of losing control over his farms, captured by the industry, if the yields fail to meet expectations in feeding the livestock.

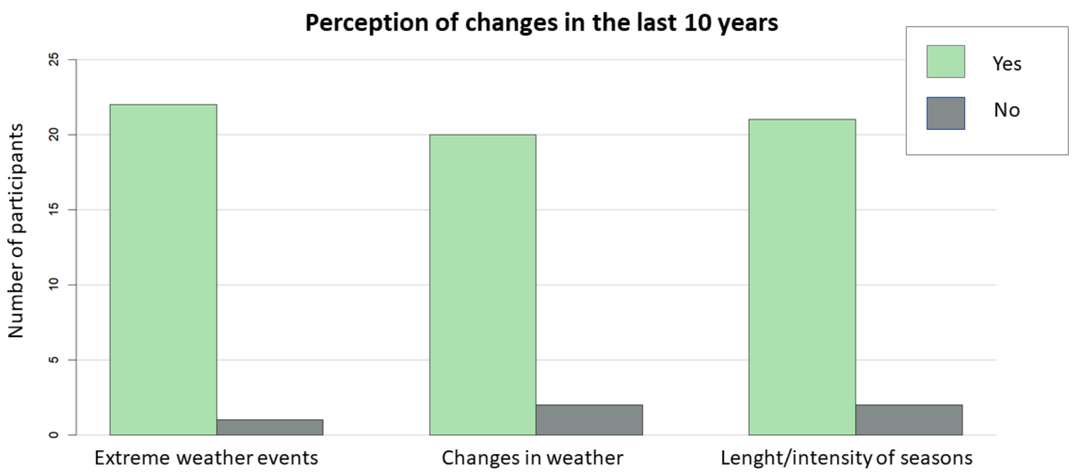
From the farmer's perspective, there seemed to be frustrations over what they perceived as a 'ruined market' (Farmer Interviewee 2). Farmers protested about 'bearing the cost of fertilisers and fossil fuels', which cut into their already diminishing profits. This would explain the general trend identified through the observation methods of farmers owning farm animals to make their own lower-cost manure, making their own natural fertiliser, or generating their own energy through solar panels (see Appendix 4). The Case Study Text Box exemplifies specific examples of financial instability of farmers in the region illustrating a vulnerability to external circumstances and actors. A large proportion expressed discontent over the influx of Ukrainian agricultural products, which they perceived as undercutting their own produce in the market. Despite the existence of EU subsidies in Europe, 80% of the survey respondents claimed to have never received any subsidies for farming.

2.3 Declining Attractiveness of Agriculture

The interviewees highlighted a concerning trend of declining interest in Agriculture altogether. According to the mayor of one of the voivodeship's towns, 'the economic role of agriculture and production is declining' due to a lack of interest and ambitions in farming activities. This sentiment is echoed by the Agricultural Advice Centre informants, who observed a pattern of young people migrating from rural areas to urban centres for education and employment opportunities.

Financially, insight from the bank informants revealed a preference towards selling their fields rather than pursuing agricultural activities; notably in reason of the 'skyrocketing' prices for agricultural land, which they deemed have doubled in the last decade. The increased demand for land development and expansion is cited by the Agricultural Advice Centre Informant as the primary driver behind this rise in prices in this voivodeship.

Farmers corroborate this trend, noting a significant decline in farming activity within their region. Individuals with multiple sources of income opted to prioritise their alternative employment, leading them to abandon farming. For approximately 20% of farmers, the lack of successors to inherit their farms emerged as a primary obstacle to sustaining their family's farming activities. In this context, a handful of farmers described their plans to rent or sell off their land to large scale farmers or for building purposes.



2.4 Climate Change

Results from the survey indicate that a majority perceived a change in the weather in the last 10 years. As can be seen in Figure 5, out of the 25 participants surveyed, 23 experienced at least one extreme weather event in the last 10 years. Only 1 out of 25 believed there had not been any change in the weather nor the length and intensity of seasons. Among those who perceived a change in the weather, over 70% (n=17) believed the climate is becoming warmer and drier and 10% (n=3) believed that it is getting wetter (Figure 6).

Figure 5. Experience of extreme weather events, perception of change in weather and intensity of seasons.

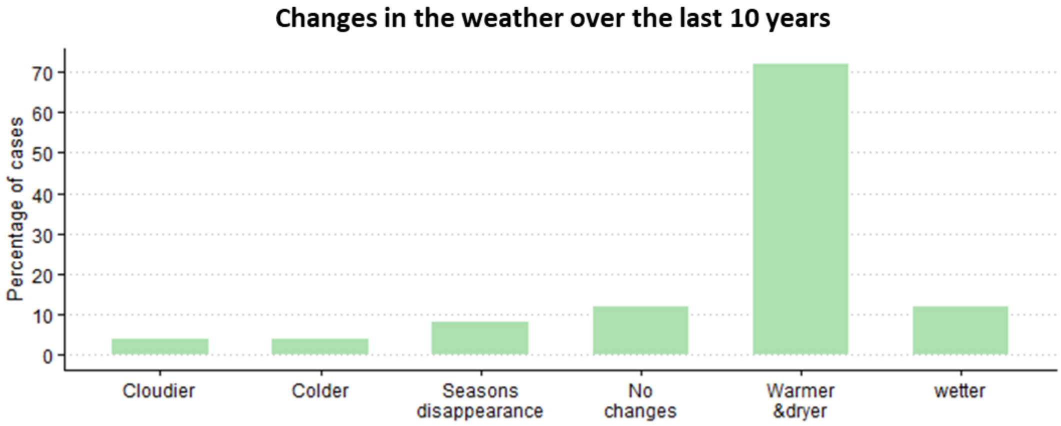


Figure 6. Responses given by survey participants to the multiple choice question "15. Have you noticed the weather changing in any of the following ways over the last 10 years?"

Looking specifically at the different extreme weather events experienced by the survey- participants, it is clear that the area is mostly affected by drought, as 80% (n=20) of the respondents experienced drought in the last 10 years. Furthermore, floods and intense rainfall were experienced by more than half of the respondents (Figure 7). Observation methods identifying flooded fields in the region further validated farmers' account of increasing floods (see Appendix 4). Finally, other extreme events such as tornadoes, hurricanes, and heat waves were also mentioned. Regarding the aftermath of extreme weather events, one third of respondents described receiving compensation and financial aid after the destruction of their farming activities after an extreme weather event.

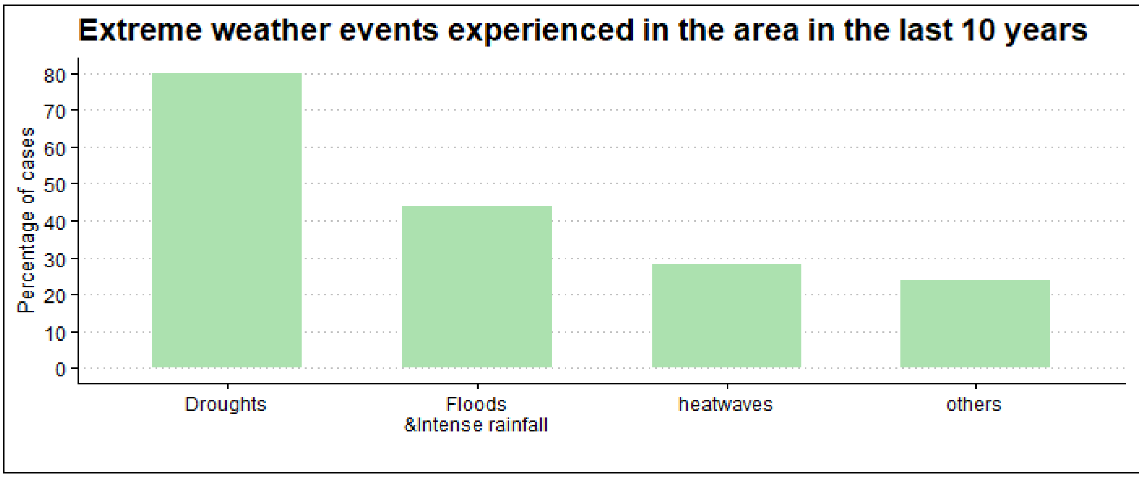


Figure 7. Responses given by survey participants to the multiple choice question "10. Have you experienced extreme weather events in the area in the last 10 years?"

The results reveal that the extreme weather threats that climate change imposes are a major concern to farmers, with 22 out of 25 participants thinking it is very likely or likely they will be exposed to these events in the coming 5 years (Figure 8).

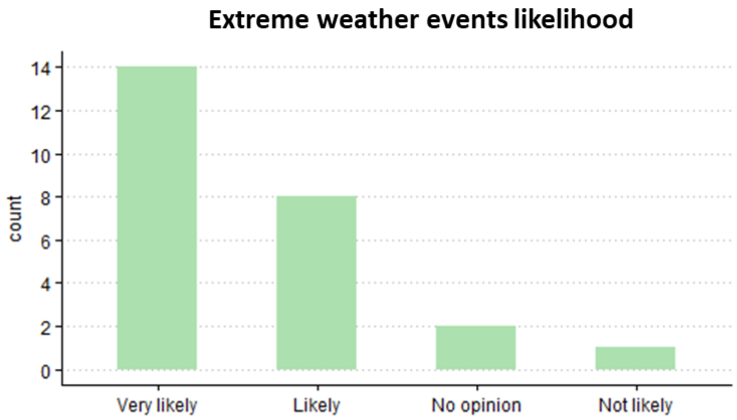


Figure 8. Responses given by survey participants to the question "14. How likely do you think this will happen in the next 5 years?"

Every farmer interviewed emphasised the adverse effects of weather on their crops. The survey results highlight that 19 out of 25 respondents perceived changes in climatic conditions as negatively affecting their crop yield, with only 3 unsure about the threat changes posed on their production. The mentioned effects encompassed reduced crop yields accompanied by diminished crop quality, with crops described as 'smaller', 'thicker', and 'drier'. Some farmers also reported earlier-than-usual harvests and pest infestations (snails) potentially linked to the weather. Additionally, excluding the three respondents who did not have an opinion, all the farmers agreed that extreme weather events affected their yield.

Given that climate change poses a significant challenge for farmers in the voivodeship, it is important to assess the extent of damage it can inflict on vegetation health. In this context, this research integrates comparative findings on variations in vegetation and crop health between 2013 and 2023.

Between the years 2013 to 2022, spanning a 3-year interval between images, changes in the quantity of vegetation can be observed, especially through the irregular frequency of vegetation on Figure 10. From 2013 to 2019 occurred an increase in vegetation frequency, visible through the appearance of more values over the 700 frequency. In 2022 there was a drop in the vegetation frequency and values were inferior to that of 2013. And for the year 2023 the frequency was considerably higher than in 2019.

Across the studied years, there were no distinguishable changes between the proportion of healthy vegetation, this can be seen on Figure 9 and validated through the frequency distribution on Figure 10. The frequency of vegetation over 0.5 (indicative of healthy vegetation) remained stable between 2013 and 2016. A notable increase in vegetation over the 0.5 threshold was observed between 2016 and 2019. Finally, in 2022 the presence of healthy vegetation was much lower than in the other three observed years. Nevertheless, in 2023 there was an increase in the values over the 0.5 threshold. On the other hand, the spreading of yellow coloration over the years in the voivodeship implies an increasing presence of stressed vegetation and unhealthy vegetation (Figure 9). The observation does not allow for specific numerical value, therefore the distribution occurrences is illustrated in Figure 10.

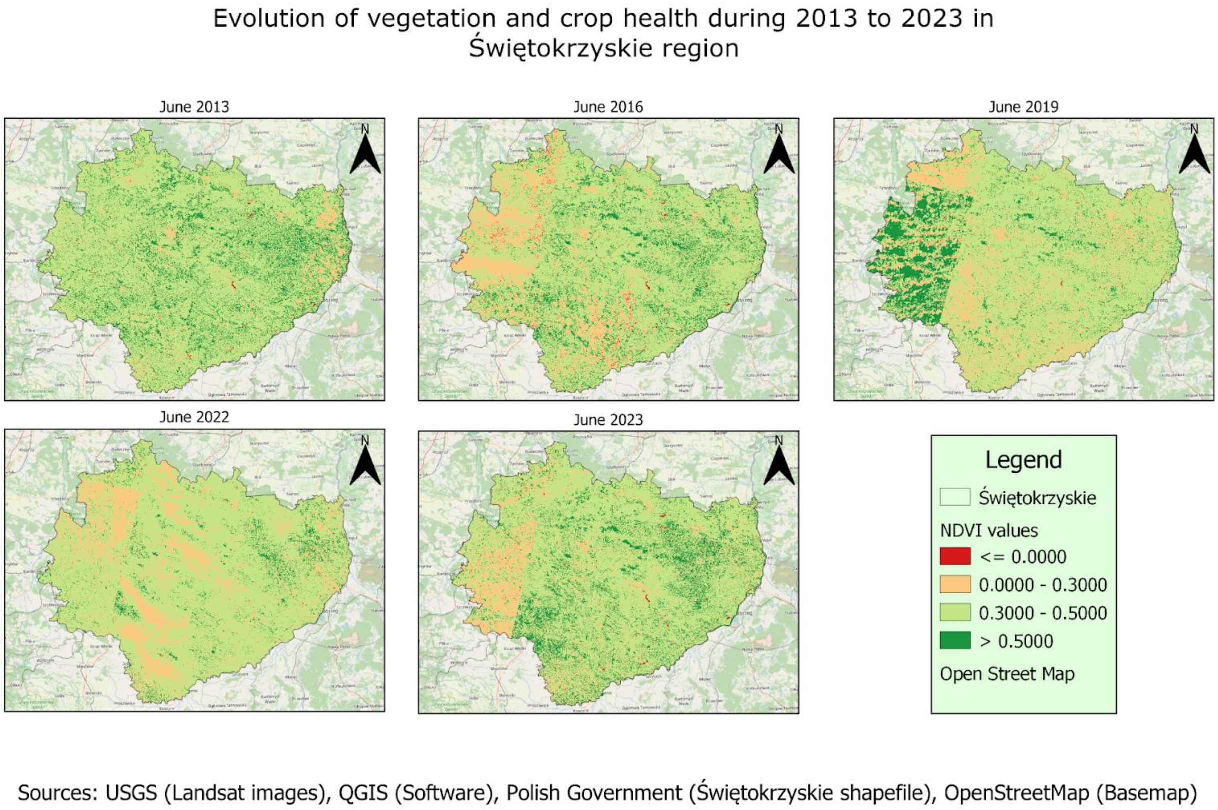


Figure 9. Evolution of vegetation and crop health during 2013 to 2023 in the Świętokrzyskie region. Own elaboration using QGIS

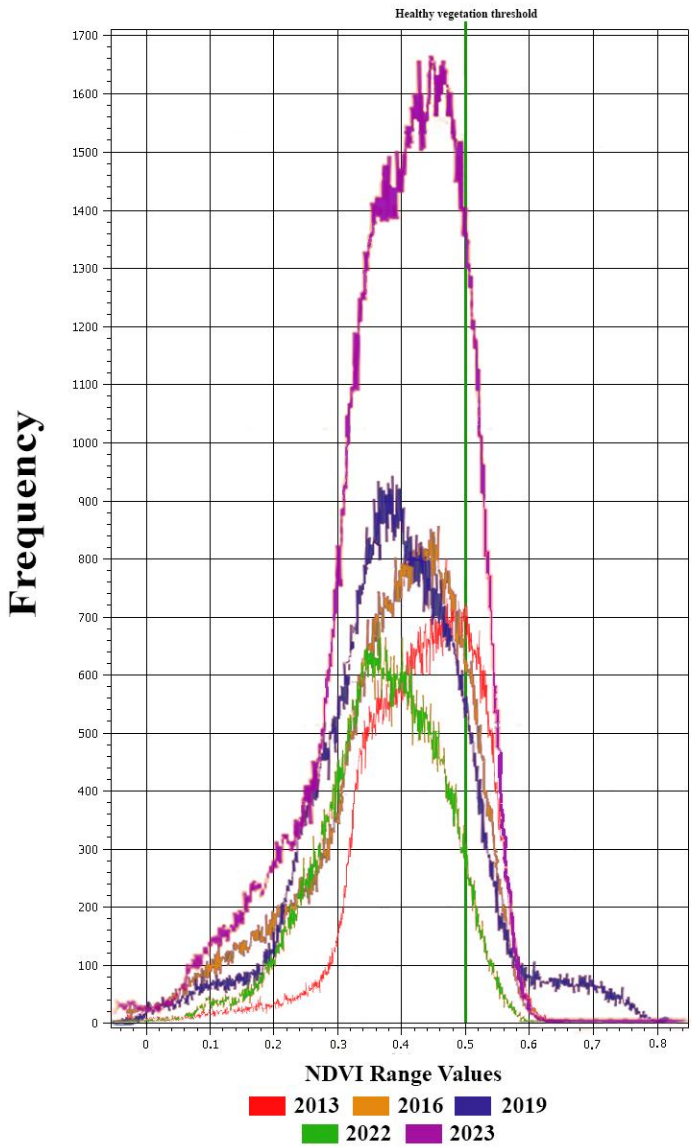


Figure 10. Frequency distribution per analysed year from 2013 - 2023. Own elaboration using QGIS and edited in Photoshop

The NDVI analysis also examined the impact of drought on vegetation health. Figure 11 illustrates a significant decline in vegetation health, evident from the considerable yellowing across the voivodeship compared to what was shown in Figure 9. In Figure 12, the distribution of values across all four cases consistently fall below the healthy vegetation threshold. The distribution of values is almost evenly split between 0 to 0.3 (unhealthy vegetation) and 0.3 to 0.5 (stressed vegetation). Values exceeding 0.5 were scarce, indicating a minimal presence of healthy vegetation in Świętokrzyskie voivodeship during this period.

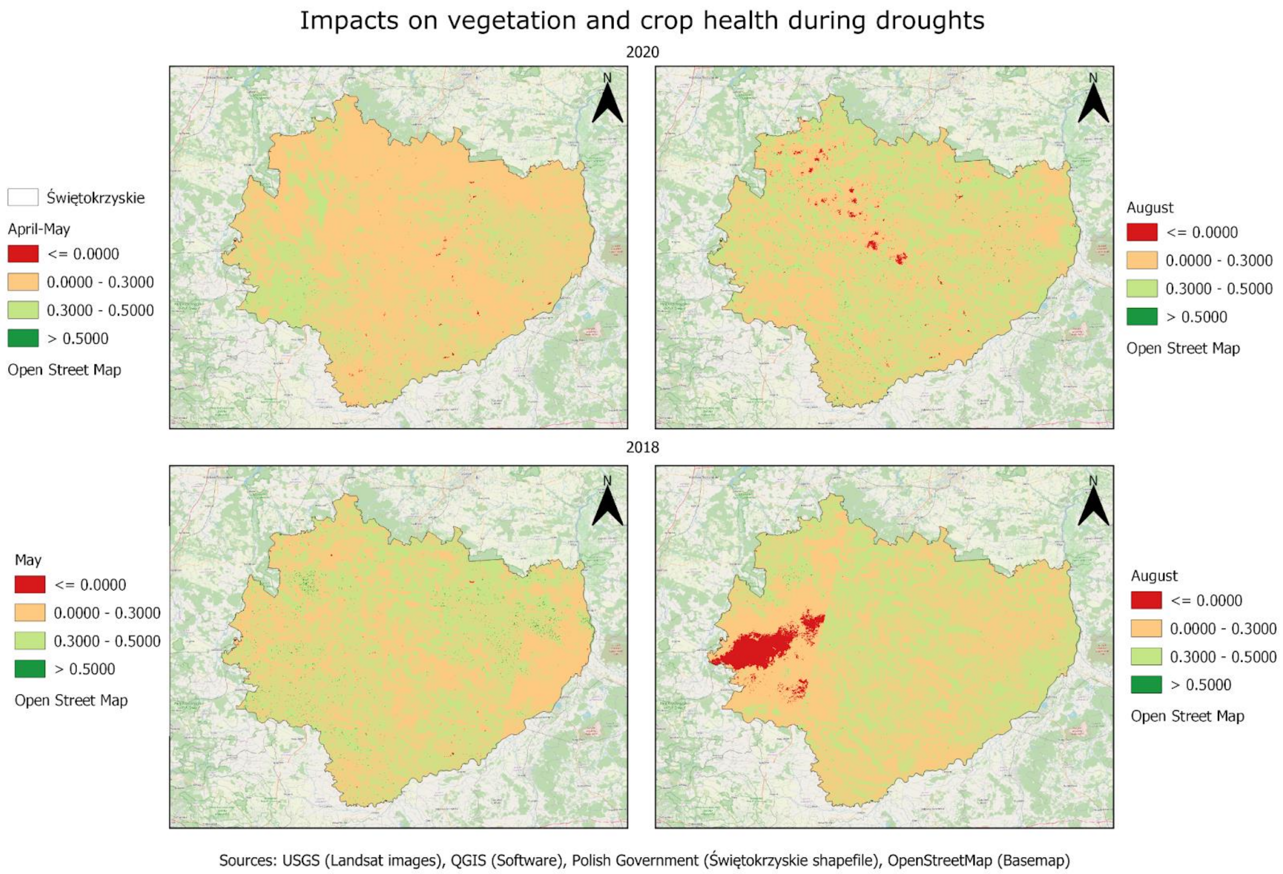


Figure 11. Impacts on vegetation and crop health during 2018 and 2020 droughts. Source: own elaboration using QGIS

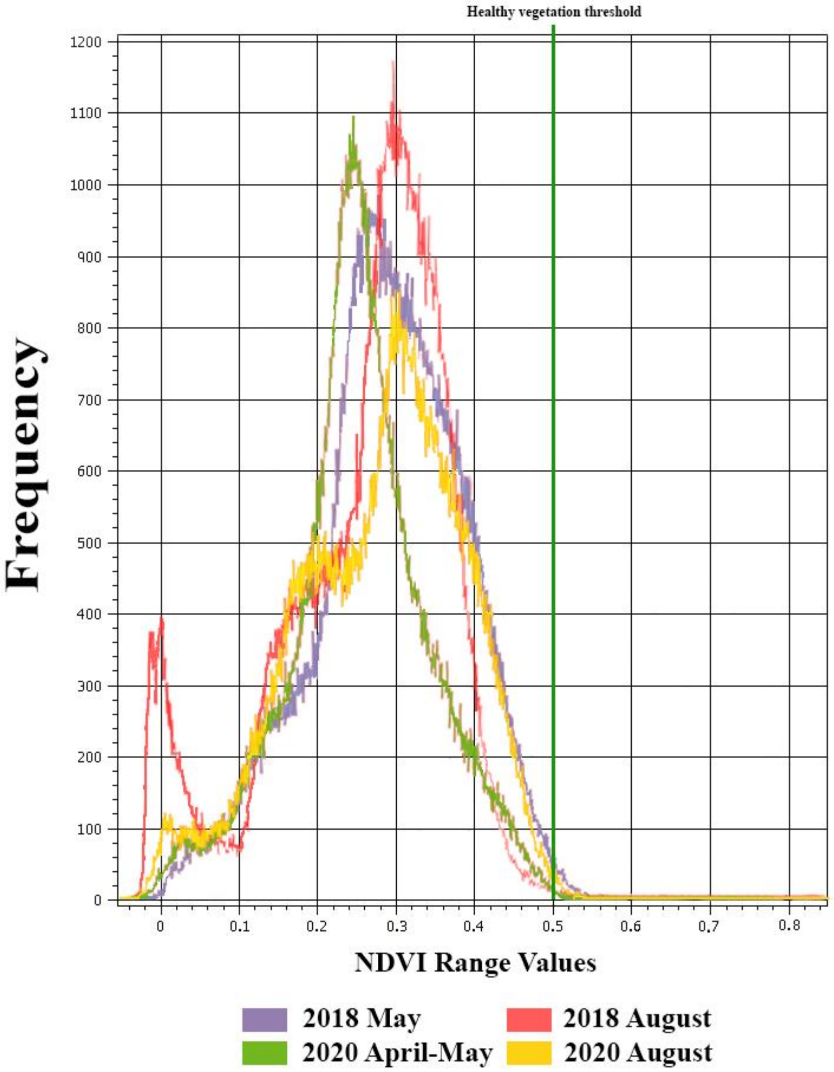


Figure 12. April-May and August frequency distributions 2018 and 2020. Source: Own elaboration using QGIS edited in photoshop

3. Adaptation Strategies to Climate Change

The interviews delved into the adaptation strategies employed by farmers to cope with the effects of climate change. Insights from the Agricultural Advice Centre revealed several key techniques adopted by farmers in the voivodeship, including planting more resilient crop cultivars, altering cultivation methods, paying closer attention to soil composition, adopting no-tillage practices, and diversifying income sources. Furthermore, the bank informants highlighted a growing trend towards ecological farming and increasing risk-mitigation strategies, including strengthening insurance coverage for winter crops and extreme weather events, as well as implementing protective measures such as anti-hail nets, cover fabrics, smoke, and water freezing prevention. This is further evidenced by the survey findings, indicating that a majority (22 out of 25 participants) have implemented new farming techniques. In terms of new agricultural methods, it is evident that crop rotation is by far the preferred option among farmers surveyed, with crop diversification ranking as the second option. Additionally, 50% of farmers also described having altered their harvesting period for their winter crops in the past 10 years due to weather changes. Despite voicing that drought was the main threat in the area, less than 10% (n=2) of surveyed farmers adopted irrigation. Similarly, with drainage, the observation remains the same, as only 4% (n=1) reported implementing drainage, despite over 40% of the respondents considered floods and intense rainfall as a concern (Figure 13).

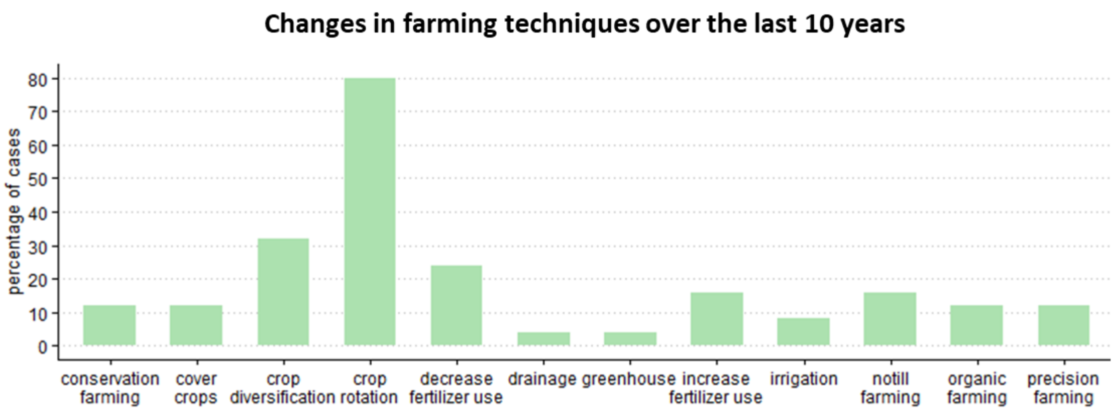


Figure 13. Responses given by survey participants to the multiple choice question “42. Have you changed your farming techniques in the last 10 years?”

Interviews with agro-industries provided additional insights into climate change adaptation efforts. While not all industries explicitly marketed their products as climate-resilient, it was evident that many had integrated this into their practices. One informant marketed their products towards precision farming (Agri-Industry Interviewee 4), while another emphasised their products' role in reducing plant stress by enhancing the crop resilience against temperature fluctuations (Agri-Industry Interviewee 5).

A cross-tabulation analysis between climate change perception and the adoption of new farming techniques revealed that over 90% (20 out of 22) of farmers who perceived a change in climate have implemented new farming techniques in the last decade. Similarly, the analysis between climate change impact on yield and the adoption of new farming techniques showed that 87% (20 out 23) of farmers who experienced a loss in yield due to climate change have adopted new agricultural practices in the last 10 years (Table 3).

Table 3. Cross-tabulation analysis between climate change perception (left table), its impact on yield (right table) and the adoption of new farming techniques.

`CC perception`	`New farming techniques`		***Total***
	No	Yes	
No	1 33.3 %	2 66.7 %	3 100 %
Yes	2 9.1 %	20 90.9 %	22 100 %
Total	3 12 %	22 88 %	25 100 %

`CC impacted yield`	`New farming techniques`		***Total***
	No	Yes	
No	0 0 %	2 100 %	2 100 %
Yes	3 13 %	20 87 %	23 100 %
Total	3 12 %	22 88 %	25 100 %

Note: *CC perception* represents the responses to "15. Have you noticed the weather changing in any of the following ways over the last 10 years?", *CC impacted yield* represents the responses to "16. Have the changes in weather conditions impacted the yield of your crops?" New *farming techniques* represent the responses to "42. Have you changed your farming techniques in the last 10 years?" questions from the survey.

Discussion

Exposure: Experience of Climate Change in the Agricultural Sector

Experiences of climate change are key elements to understanding the exposure of farmers to climate change (Arbuckle *et al.,* 2013; Niles *et al.,* 2015; Niles and Mueller, 2016; Vani, 2016) (Figure 1).

The findings from this study reveal that nearly all, if not all, of the 25 farmers surveyed had noticed changes in weather patterns, referring to shifts in the duration and intensity of seasons, and a trend towards a warmer and drier climate. This observation aligns with established scientific knowledge.

Estimates of mean annual temperatures over the last 40 years in the Świętokrzyskie Voivodeship identify a positive trend towards a warmer climate in the region. The following data is sourced from the ERA5, the fifth generation of ECMWF atmospheric re-analysis for global climate, covering the time frame from 1979 to 2021. Visual representation of this trend is depicted in Figure 14, showcasing the average annual temperature for the Świętokrzyskie Voivodeship. The dashed blue line illustrates the linear trend of climate change, where an upward trajectory indicative of warming temperatures is demonstrated. The lower portion of the chart displays anomaly strips, with each coloured bar representing the yearly temperature increase or decrease from the baseline; 30 year climate mean of 1980-2010, - blue for colder years and red for warmer years. This graph underscores the consistent increase in temperature observed in the region (Meteoblue, 2023).

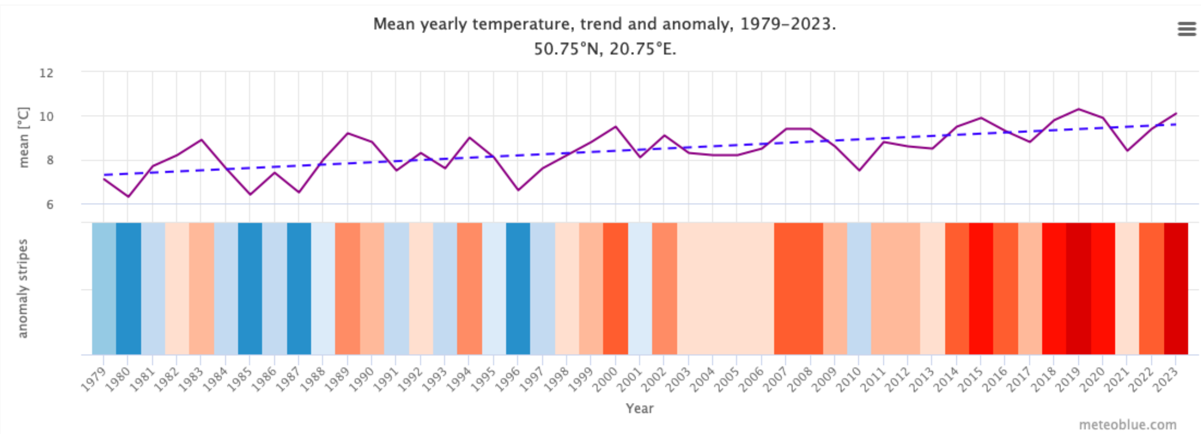


Figure 14. Mean yearly temperature, trend and anomaly in Świętokrzyskie Voivodeship from 1979-2023 (Meteoblue, 2023)

Farmers not only perceived changes in the climate but also directly experienced climate variability and extreme weather events. Nearly all of the participants encountered extreme weather events within the past decade, with droughts, floods, and intense rainfall cited as the most prevalent threats. These findings align with scientific research and meteorological data.

Flooding and drought emerges as primary natural risks in Poland. Data from the European Severe Weather Database indicates a rising trend in flood events over the past half-century, with some of the most severe incidents occurring in 1997, 2001, 2010, 2017, and 2021 (Pinskwar *et al,* 2018). In June 2020, heavy rain affected the provinces of Podlaskie, Masovia, Świętokrzyskie, and Małopolskie. Additionally, high temperatures and drier climate conditions contribute to drought risk. Some of the most notable droughts in Poland occurred in the years 1992, 1994, 2003, 2006, 2008, 2015, 2018 and 2020; causing devastating effects, especially on crop yield loss (Aalbers *et al,* 2023; Pinskwar *et al,* 2018). After drought intense rainfall poses a higher challenge as dry land struggles to absorb water efficiently. This circumstance heightens the risk of flash floods, particularly in urban areas and agricultural land (Pinskwar *et al*, 2018).

These results validate Hypothesis 1.1, which suggests a widespread perception and experience of changing environmental conditions in the voivodeship. The findings strongly indicate that populations in this area are highly exposed to climate changes, a crucial aspect in assessing farmers' vulnerability.

Previous research highlights that positive perceptions of climate change is a primary motivator for adaptation efforts (Frank *et al.*, 2011; Tompkins *et al*., 2010). If farmers do not believe in climate change; they are less likely to perceive it as a threat to their livelihoods and consequently; they may put in less effort to adapt and mitigate its impact (Dietz, 2015). Specifically, dramatic climate-related events, such as the extreme weather events experienced, are highlighted as significant drivers for adaptation responses (Berrang-Ford *et al.,* 2011; Jamshidi *et al,* 2019). The impact of these events on adaptation will be evaluated in a subsequent section.

The research also explores whether climate change is perceived as a future risk, beyond mere exposure. The results indicate that extreme weather events associated with climate change in the future are a major concern for participants, with almost all respondents expressing that it is likely or very likely that they will be exposed to these events in the next 5 years. These findings, validating Hypothesis 1.2, underscore the perception of a significant exposure and vulnerability of farmers to extreme weather events.

Not only are farmer's perception of climate change crucial to assessing their vulnerability; understanding farmers' perceptions are vital for policymakers, as it aids in comprehending their adaptive attitudes and facilitates the design of effective policy measures. Moreover, understanding how socio-cultural and economic factors influence climate perceptions can assist in integrating climate education and communication into adaptation research, aiding in the comprehension of climate impacts and responses at the farm level (Nguyen *et al.,* 2016).

Sensitivity: Impact of climate change on agricultural productivity

As a part of the vulnerability framework, sensitivity explains how susceptible the system is to climatic disturbances (Figure 1). This section explores the impact of climate change on agricultural productivity, encompassing the overall experiences of farmers and supplementing them with analyses of soil, which forms a foundation of agricultural activities, and vegetation health.

A majority of farmers expressed concerns about the adverse impact of weather conditions on their crops. Out of all the farmers surveyed around 75% of participants reported experiencing negative effects on their crops over the last 10 years. Within the sample approximately 75% of participants have been engaged in farming for more than 10 years, which constituted the timeframe investigated in the survey (Figure 3).

The impact of climate change on yields and crop quality was discussed in terms of crop quality and yield. Due to climate change farmers described their crops being of weaker and poorer quality, as well as having overall lower yields, making it hard to profit from the soil. The effects of climate change in this region might have been particularly important due to the fact that farmers primarily grow cereals and potatoes (Figure 4). This monocultural practice decreases the resilience of crops towards extreme climatic conditions, pests, and diseases (INRAE, 2022). Moreover, nearly all farmers acknowledged that extreme weather events specifically affected their crop yields. Additionally, one respondent reported pest infestation by snails as a consequence of climate changes, a concern also documented in Italy, suggesting a potential link between weather events and infestation (Nguyen *et al.,* 2016). Overall, the Hypothesis 2.1 that farmers perceived a decrease in productivity due to environmental changes is validated.

The perception of farmers regarding vegetation quality and health is complemented by the NDVI analysis. The data spanning from 2013 to 2022 indicates a stagnation in the proportion of healthy vegetation present in the voivodeship and an increase in unhealthy vegetation. This was possibly influenced by factors such as droughts, floods, and other extreme weather events. A deviation from this trend is observed in 2023, where the frequency distribution values closely resemble those of 2013. This suggests that despite a possible trend towards the degradation of vegetation health over the years, a potential reversal of the trend is possible. Such reversal could be attributed to reduced occurrences of extreme events, favourable climatic conditions, or implementation of conservation policies. Disregarding the increase in healthy vegetation of 2023, and vegetation growing up, stagnating between the same values over the years, most of the 'new' vegetation appeared below the 0.5 threshold. This could suggest that the 'new' vegetation, vegetation that was not there before, shown in the frequency distribution graphs, is not growing as healthy vegetation but rather as stressed and unhealthy. In this context, the majority of vegetation in the Voivodeship is stressed and unhealthy.

Access to older spatial images would have been valuable in order to observe more clearly the evolution of the quantity of healthy, stressed and unhealthy vegetation across time. At present, since there is no clear indication of the proportion of healthy vegetation declining due to the stagnation, definitive conclusion cannot be drawn regarding the Hypothesis 2.2, that vegetation health has declined across time. However, it can be noted that new growth of vegetation is tending towards stressed and unhealthy vegetation, which could represent a considerable challenge for the future of agriculture since there is not a visible improvement on its health.

Drastic declines in vegetation health were observed during periods of documented droughts. Throughout these months, the vegetation in Świętokrzyskie predominantly fell within categories of unhealthy and stressed vegetation, despite slight improvements observed from May to August. The absence of healthy vegetation during these periods raises alarm about the potential impacts on ecosystems and soils, which are crucial to agricultural productivity and development. While the exact repercussions of this decline on ecosystems and soils remains uncertain, it is evident that droughts negatively impact the vegetation health in Świętokrzyskie voivodeship, thus validating Hypothesis 2.3. An escalation in the frequency and intensity of droughts in the future could pose significant risks to agriculture.

The research further examined changes in soil quality over time (2015, 2018 and 2024), using pH and organic C as indicators. This analysis offers a potential avenue to understand the influence of climate change on soil conditions.

pH serves as a critical parameter in assessing soil quality, as it influences nutrients availability for plant uptake and plays a crucial role in fostering adequate microbial development and soil structure (Kumar *et al.,* 2023). In the current study, a statistically significant increase in the pH value is reported

through a 10 year period. Several factors could explain these findings. Climate change has been extensively linked to soil pH variations (Mondal, 2021; Rengel, 2011; Tóth, 2013). However, the impact of climate change has been generally associated with soil acidification (decrease in pH values) (ibid). Since there is no previous record of pH increasing as a result of climate change, there is not enough evidence to argue that the observed changes are caused by this phenomenon.
On the other hand, the timing of the sampling may have played a crucial role, as the LUCAS database sampling occurred from May to August, whereas the present study was carried out in March. It is not uncommon that pH shows seasonal variations (Vašák *et al.,* 2015). Additionally, agricultural practices such as liming and fertilisation can significantly affect the pH of the soil. Due to the lack of background information on farm management practices where soil samples were collected, it is not possible to know if these types of techniques were applied. Furthermore, according to Kumar *et al.* (2023) the optimal range of pH in soil for most crops falls between 6 and 7. Although the pH has increased in the sampled sites it stays within the recommended threshold. Consequently, the reported change in pH does not indicate that the quality of soil has decreased. Regarding organic C content, no statistically significant difference was detected across time.

Overall, the parameters analysed throughout time do not show a decrease in soil quality. The methods used in the present report are therefore insufficient to validate Hypothesis 2.4. More parameters would be needed to adequately describe the changes in soil characteristics over the last 10 years. Other indicators to assess the quality of a particular soil include base saturation, soil respiration, microbial biomass C, particle density, total porosity, and aggregate stability (Maikhuri, Rakesh & Kottapalli, 2012). In the present report, pH and organic C were used as broad approximations considering time and previously mentioned technical constraints, as well as the available data from previous studies.

While there is no established correlation between the climate change and soil quality, it is valuable to consider potential future challenges the soil may encounter when sustaining crops production with regards to changing climate. By examining soil conditions from specific farms, this study assessed the resilience of the soil to drier climate using pH, C/N ratio and WHC. Farmers surveyed exhibited a strong concern about the declining soil quality attributed to, in their opinion, various factors such as the impacts of droughts and rising temperatures as well as the absence of fertilisers and livestock for soil nourishment, due to their high cost. The survey revealed that 15 out of 25 of the farmers perceived changes in soil quality, with soil acidity and reduced fertility being among the primary concerns.

During periods of limited precipitation, water holding capacity (WHC) can compensate for water scarcity (Zhang *et al.,* 2021). Not all the water volume in the soil is available for the plant to use, and the WHC reflects the soil's capacity to provide water to plants (ibid). Both the soil texture and organic matter plays a significant role in determining WHC (Husted, 2009). The measured WHC of farm soils falls within the range of 21.26 - 33.90% (Table 2), aligning with the typical range of soil water retention, reported to be between 0-43% when organic matter is not considered (Husted, 2009).

Water binds to soils in accordance with conductivity, where clay has the greatest conductivity and sand the least (Connor *et al.*, 2011). The farms in the study exhibited a range of soil texture, spanning from loamy sand to clay loam (Table 2). According to the USDA soil triangle, different soil textures correspond to a varying clay content: loamy sand with 0-15% clay content, sandy loam with 0-20% clay content, loam with 10-28% clay content, and both silty clay loam and clay loam with 28-40% clay content (Husted, 2009). This suggests that Farm 19 should have had the highest WHC and Farm 2 should have had the lowest. However, in contrast to this expectation, Farm 19 exhibited the second to lowest WHC, while Farm 2 exhibited the highest value (Table 2). Such discrepancy could be attributed to errors in the laboratory, faulty measurement of WHC, or subjective interpretation of the finger method used to determine soil texture. It is important to point out that soil texture is an inherent parameter that is not easily altered through management practices, unlike organic matter, which is a dynamic parameter that can be adjusted through management (Husted, 2009).

Soil organic carbon (SOC) and organic matter are closely linked with 58% of organic matter comprising SOC. Due to the difficulty of measuring organic matter directly, SOC serves as a reliable indicator of soil quality and organic matter (Lal, 2022). The SOC in the farms ranges from 8.0-19.4 g/kg soil (Table 2). These measurements are analysed under the assumption that organic carbon equals total carbon. The SOC correlates with the WHC range, where Farm 1 exhibited the highest values with SOC of 19.4 and WHC of 33.90, and Farm 8 had the lowest values with SOC of 8.00 and WHC of 21.26. Variations between the expected pattern and observed data, between Farm 1 and 5, could be explained by the introduction of additional organic matter into the sandy soil. Sandy soils are characterised as poorer soils due to their low clay content, wherefore they often benefit from the addition of organic matter to enhance WHC (Husted, 2009).

These results suggest that all the farms' soil have a considerable reservoir of water within their soil. Surprisingly, the sandy soil with the lowest clay content exhibited the highest WHC because it has a high organic matter content. This finding indicates that soils with higher clay content could potentially increase the WHC through addition of organic matter. This management strategy could make the soil retain more water whereby it becomes additionally adaptable to drier climates.

Although the ideal pH for plant growth falls within the range of 6-7, most crops can tolerate pH levels ranging from 5-8 (Connor *et al.,* 2011). The pH levels among the farms range from 6.3 to 8.1 (Table 2). Additionally, the farmers reported that they mostly cultivate wheat, oats and potatoes. The ideal pH for wheat is between 6-7 (Vitosh, 1998), for oats it ranges from 4.5-6 (Curell, 2012), and potatoes require a pH of 5.5-6.5 (Sánchez *et al,* 2023). In this context, Farm 2 and 8 have pH levels that are too high for the crops commonly produced. Farm 8 even has a pH level leaning towards an unsuitable level for general crop growth, where some essential nutrients become unavailable for plants (Connor *et al,* 2011). Additionally, Farm 8 might encounter issues when ammoniacal fertilisers are used, as the combination of a high pH and dry soil can result in significant volatilization of this form of nitrogen (Connor *et al.*, 2011). Hereby the obtained results highlight the importance of considering the interaction between weather disturbances and soil pH, especially when the soil already presents unsuitability relative to the optimal benchmark.

The nitrogen level across the farms ranges from 1.3-1.8, with Farms 8 and 19 exhibiting levels too low to be detected (Table 2). The value of total N content includes both the N available to plants and the non-mineralized portion of this element. However, it has been suggested as an useful indicator of the total potential of a soil for N mineralization (Liptzin et. al, 2023). It is important to recognize that the recommended values for this indicator will vary considerably according to factors such as soil type, land use, crops grown and fertilisation. In the Świętokrzyskie Voivodeship, local guidelines or sufficient literature providing a reliable source to compare the obtained values are lacking. Nevertheless, it is possible to contextualise the obtained amount with values reported on similar studies. In a report where 153 samples were studied from 17 fields of potatoes, corn and cereals in the USA, a mean value of 1.90 g/kg of total N was obtained (Sharifi, 2007). In another study where croplands from the Loes Plateau region in China were evaluated, the mean value for N was 0.81 g/kg (Liu et. al, 2013). Therefore, the range reported in the present study cannot be considered extremely low or high. Nitrogen and carbon can also be associated in a C/N ratio. The ratios for the farms were 11/1 and 12/1 (Table 2) which fits with the standard C/N ratio of 10/1-13/1 in agricultural soils (Connor *et al.,* 2011) indicating a balanced C/N ratio.

As suggested by Seybold, Herrick and Brejda (1999) it is possible to utilise similar indicators employed in assessing soil quality to evaluate the resilience of soils. This is due to these parameters being essential for the soil to recover after any type of disturbance (ibid). In the present study, the indicators utilised provide no indication to suggest that the soil lacks resilience to climate change. Parameters such as WHC, pH and C/N ratio fall within the standard values of normally functioning soils, thereby rejecting Hypothesis 2.5. These results do not imply that the soil in the area is immune to risks associated with climate change. Rather, they suggest that under adequate management it would still be possible to maintain soil quality and fertility under changing weather conditions, factors that are naturally concerning farmers.

Adaptive Capacity: Adaptation of Agriculture to Climate Change

Given the constant changes in the weather patterns, actions are needed to enhance the resilience of agricultural practices to climate change or at least mitigate its negative impact. A notable observation from interviews conducted with farmers revealed a widespread implementation of new farming techniques in the last decade. The following results are discussed to assess whether these new farming techniques are specifically implemented in response to climate changes.

In contrast to findings from prior studies, where surveyed farmers preferred using resilient crop cultivars as a response to climate change (Macholdt & Honermeier, 2016, Micu *et al.,* 2022, von Gehren *et al.,* 2023), the predominant strategy reported by a majority of farmers in this study was the practice of crop rotation, followed by crop diversification (Figure 14). Considering the information gathered from the Interview with the Agriculture Advice Centre and previous literature mentioned, which highlighted resilient cultivars as a prominent adaptation strategy amongst farmers, a higher selection of this adaptation option was anticipated. The language barrier encountered during this study may have contributed to a misunderstanding of this terminology by the farmers surveyed, possibly resulting in their failure to select it as an adaptation strategy.

Regarding the predominant adaptation strategies reported, previous studies have highlighted the efficacy of both crop rotation and diversification in increasing the resilience of agriculture against the impacts of climate change (Farina *et al.,* 2018; Sehgal *et al.*, 2023). Particularly interesting given that more than 80% of surveyed farmers identified drought as a principal challenge in the area, crop rotation is recognized as a viable solution to making agriculture production more resilient to abiotic stresses (Degani *et al.*, 2019).

Furthermore, a significant proportion of farmers adjusted their harvesting schedules as an adaptation to climate change, aimed at mitigating crop losses during the dry and hot summer months. Insights from key informant interviews further highlight that farmers are increasingly engaging in no-tillage practices, implementing protective measures towards extreme weather events and enhancing risk mitigation measures, such as strengthening insurance coverage for winter crops and extreme weather events. These proactive responses are justified by the rising frequency of extreme weather events, necessitating enhanced protection measures. Overall, these findings seem to point towards a possible adaptive capacity of agriculture to climate change with a clear preference towards utilising cost-effective methods to cope with climate variability.

An interesting aspect for discussion regarding adaptation techniques is the discrepancy observed between farmers identifying droughts as the primary threat in the area and the limited adoption of irrigation. While irrigation is an effective technique to reduce the effect of drought on agricultural production, its underutilization could be attributed to the high costs associated with irrigation systems or a possible lack of ground and surface water, compounded by the lack of subsidies and economic support for farm management reported by farmers. Observations regarding drainage reflect a similar trend, with only 4% of farmers implementing drainage systems despite almost half of farmers expressing concerns about floods and rainfall. Although some Agri-Industries propose adaptation technologies aimed at precise irrigation or at reducing plant stress and enhancing resilience to temperature fluctuations, it seems that farmers in this voivodeship are inclined towards low-cost adaptation methods, primarily due to the prevailing price sensitivity among them.

As noted in previous studies, experiences of climate change and its negative impacts often drive adaptation actions (Frank *et al.*, 2011; Nguyen *et al.,* 2016; Tompkins *et al.*, 2010). In this study, 88% of respondents experienced and acknowledged climate change as well as implemented new farming techniques, while 88% experienced yield loss due to climate change as well as implemented new farming techniques. Given that the cross-table analysis suggests a correlation between experience of climate change and yield loss due to climate change with new farming techniques, a statistical test, such as the Chi-squared test, could have provided valuable insights about whether the surveyed farmers implemented new agricultural methods as an adaptation strategy to climate change and its impact on agricultural productivity. However, the sample size is insufficient to conduct such statistical analyses (White, 2003).

Overall, the conflicting nature of the results, with a possible trend towards adaptation to climate change identified in interviews put into perspective with a lack of adaptation to the most important extreme weather issues encountered by farmers; in addition to the constraints imposed by the limited samples on statistical analysis, no clear conclusions can be made regarding Hypothesis 3.1.

Furthermore, adaptive capacity can also be significantly influenced by various other variables (Jamshidi *et al.,* 2019). In this particular voivodeship, economic struggles within agriculture had a substantial impact on adaptive capacity. The inflation of fuel and fertiliser prices, coupled with the influence of geopolitics on the global agricultural market creates an environment where agriculture profitability is compromised. Furthermore, the high price sensitivity of farmers impeded their ability to access external assistance, such as loans from banks. The absence of a structured support system for farmers, including EU subsidies and assistance following extreme weather events, further undermines their ability to cope with climatic changes. In this context Hypothesis 3.2 is refuted.

Overall, whether due to economic struggles associated with agriculture or the allure of alternative opportunities, there has been a noticeable decline in appeal in farming activities. Given the reported circumstances, where farmers may prioritise selling or renting their land rather than pursuing agricultural activities, it is apparent that investment in adaptation to climate change may not be a priority to farmers. Indeed, to the extent that agriculture primarily serves as a means of subsistence for most farmers surveyed, contributing only 25% of their income, it seems reasonable to suggest that adaptation to climate change may not necessarily be the primary concern for them at the moment of the study. This trend aligns with the broader phenomenon observed in the voivodeship, of individuals diversifying their income due to the inherent vulnerability of agriculture, often engaging in multiple occupations simultaneously or abandoning agricultural practices altogether.

Positionality

This discussion highlights the interdisciplinary dynamic within the research group, serving as a valuable asset in exploring diverse angles of agricultural vulnerability to climate change. Leveraging this interdisciplinary approach, enabled a cross-reference and triangulation of the data to fortify the analysis of the results. However, navigating different backgrounds posed a challenge, particularly in reconciling differing report writing strategies between social and natural sciences, in aligning research methods and scope of the research and in incorporating feedback from different research fields. Nonetheless, while interdisciplinary collaboration may entail potential conflicts, it undeniably enriches the research process (Hill *et al.*, 2008).

Moreover, from the perspective of the participant in the research, the research group was perceived as specialised foreign university students. Such perception potentially influenced various aspects of the study, including participant willingness to engage (Hurst, 2023). Interviews and surveys may have been influenced by some bias, for example, if participants did not honestly recount their experiences. This scenario could have arisen if they felt incentivized to alter their behaviour and motivations for personal gain. To mitigate such biases, a sampling method aimed at limiting bias of population sampled was established through external incentives.

Positioned as students from Environment, Development and Agriculture, qualifying the research group as ‘insiders’ to this interactive research, facilitated a comprehensive understanding of the research's scope (Ugoretz, 2017; Holmes, 2020). Previous engagement with climate change, cultivating preconceptions towards the importance of climate change and usefulness of adaptation techniques in agriculture, may have influenced the interview questions and interpretation of data collected. Efforts were made to develop an interview strategy that did not steer participants towards a specific direction, and to analyse data with reference to existing literature.

In summary, this research contributes to a better understanding of the impact of climate change on the agricultural conditions of the Świętokrzyskie Voivodeship of Poland. Tailored, authentic data enables a broad understanding of the phenomenon at stake (Opdenakker, 2006), despite limitations existing regarding its generalisation due to climate variability, soil properties and socio-economic environment across the region.

Conclusion

The vulnerability assessment highlights that a significant proportion of smallholder farmers are facing vulnerability to climate change. Farmers struggle with climate variability and extreme weather events, which not only affect their production but also impacts their livelihoods. Corroborating these findings, NDVI results indicate that most of the vegetation is growing below the healthy threshold, with vegetation health notably affected by droughts. This confirms the direct threat posed by climate change to agricultural practice in the voivodeship. While soil analysis did not reveal alarming values for most of the evaluated parameters, in some cases deviations from optimal conditions were manifested. Nonetheless, the analysed soil still presents characteristics conducive to adaptation to changing weather conditions under the appropriate management, unveiling an urgent need of action before the effects of climate change become irreversible.

Despite farmer's exposure and sensitivity, the findings underscore the reality that farmers lack sufficient adaptive capacity without external assistance. In the case examined, the geopolitical context and dynamics of the agricultural market, which render farmers highly price-sensitive, emerges as a significant influence of this vulnerability and lack of capacity to cope with climate change. Efforts to bolster farmers' adaptive capacity to climate change should be a priority on policymakers' agendas, notably through education, financial support, regulatory measures, political backing, and the effective planning of adaptation programs. Strengthening these efforts is essential for empowering farmers to better navigate the challenges posed by climate change and safeguarding agricultural livelihoods in the face of increasingly unpredictable environmental conditions.

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Appendix 1. Methods Table

METHODS	SAMPLE/INFORMATION	ANALYSIS	SOFTWARE
Survey	25 respondents	Descriptive statistics	R(version 4.3.2)
Semi-structured interview	12 semi-structured interviews were conducted with the Agricultural Advice Center, the mayor of one of the Voivodeship towns, key informants from a local bank, and agro-industries.	Qualitative Analysis	NVivo (version 14.23.3(61))
Observation	Information about agricultural methods, and technologies used by farmers was gathered	Qualitative Analysis	
Soil sampling and analysis	8 samples from LUCAS's coordinates 5 samples from farmers farms surveyed	pH, WHC, Total N and C and texture Kruskall-Wallis test followed by pairwise comparisons using Wilcoxon rank sum exact test Descriptive statistics	R (version 2023.06.1)
Normalized Difference Vegetation Index (NDVI)	10-year (2013-2023) imagery from Landsat obtained through USGS	Quantitative analysis	QGIS Photoshop

Appendix 2. Survey Guide (English Version)

Demographic variables

1. Gender

2. Occupation

3. Age
- ◻ less than 30
- ◻ 30-40
- ◻ 40-50
- ◻ more than 50

4. Highest education
   - ◻ Secondary school
   - ◻ High-school
   - ◻ Technical University
   - ◻ University
   - ◻ Other

5. How long has your household been engaged as a farmer?

6. How long have you been living in Kielce county?

7. What is the size of your farm?
   - ◻ Less than 1 ha
   - ◻ 1-5 ha
   - ◻ 5-10 ha
   - ◻ 10-15 ha
   - ◻ More than 15 ha

8. Which type of farming are you practising?
   - ◻ Commercial
   - ◻ Subsidence
   - ◻ Both
9. What percentage of your income pertains to farming?
   - ◻ 0 - 25%
   - ◻ 25 - 50%
   - ◻ 50 - 75%
   - ◻ 75 - 100%

Perception and experience of changing environmental conditions

10. Have you experienced extreme weather events in the area in the last 10 years? If you have, please select all that applies to you.

- ◻ No extreme weather events
- ◻ Floods
- ◻ Droughts
- ◻ Cyclones
- ◻ Heatwaves
- ◻ Forest fires
- ◻ Intense and prolonged rainfall
- ◻ Landslides
- ◻ Freezes
- ◻ Large sized hail
- ◻ Other _____

11. Have these events had an impact on your farm yield?
    - ◻ Yes
    - ◻ No
    - ◻ I don’t know
12. Did you get any compensation for these damages?
    - ◻ Yes
    - ◻ No
13. How common are these events in Kielce county?
    - ◻ Every year
    - ◻ Less than 5 years
    - ◻ Less than 10 years
    - ◻ Less than 20 years

14. How likely do you think this will happen in the next 5 years?
    1- not very likely
    2- not likely
    3- neutral
    4- likely
    5- very likely

15. Have you noticed the weather changing in any of the following ways over the last 10 years? Please select all that apply.
    - ◻ It hasn’t changed
    - ◻ Warmer
    - ◻ Colder
    - ◻ Cloudier
    - ◻ Wetter
    - ◻ Dryer
    - ◻ Other _____

16. Have the changes in weather conditions impacted the yield of your crops?
    - ◻ Yes
    - ◻ No
    - ◻ I don’t know

17. If Yes: In what way have they impacted your ability to grow certain crops?

18. Have the intensity and/or length of seasons changed over the last 10 years?
   - ◻ Yes
   - ◻ No
   - ◻ I don't know

Production

19. What types of crops did you produce in the last year?
   - ◻ Wheat
   - ◻ Rye
   - ◻ Oats
   - ◻ Corn
   - ◻ Potatoes
   - ◻ Turnip rape
   - ◻ Sugar beets
   - ◻ Other _____

20. Were you growing the same crops 10 years ago?
   - ◻ Yes
   - ◻ No
21. If no: What has changed? What is the reason for this change in crop production?

22. If Yes: Were you growing them in the same proportion 10 years ago?
   - ◻ Yes
   - ◻ No
   - ◻ I don't know

23. Do you practise crop rotation?
   - ◻ Yes
   - ◻ No

24. When are you sowing/planting your winter crops?
   - ◻ January
   - ◻ February
   - ◻ March
   - ◻ April
   - ◻ May
   - ◻ June
   - ◻ July
   - ◻ August
   - ◻ September
   - ◻ October
   - ◻ November

- □ December

25. Was this the same period of harvest 10 years ago?
    - □ Yes
    - □ No
    - □ I don't know

26. If No: What is influencing the changing crop calendar?

27. When are you harvesting your winter crops?
    - □ January
    - □ February
    - □ March
    - □ April
    - □ May
    - □ June
    - □ July
    - □ August
    - □ September
    - □ October
    - □ November
    - □ December

28. Was this the same period of harvest 10 years ago?
    - □ Yes
    - □ No
    - □ I don't know

29. If No: What is influencing the changing crop calendar?

30. When are you sowing/planting your spring crops?
    - □ January
    - □ February
    - □ March
    - □ April
    - □ May
    - □ June
    - □ July
    - □ August
    - □ September
    - □ October
    - □ November
    - □ December

31. Was this the same period of harvest 10 years ago?
    - □ Yes

- ◻ No

32. If No: What is influencing the changing crop calendar?

33. When are you harvesting your spring crops?
    - ◻ January
    - ◻ February
    - ◻ March
    - ◻ April
    - ◻ May
    - ◻ June
    - ◻ July
    - ◻ August
    - ◻ September
    - ◻ October
    - ◻ November
    - ◻ December

34. Was this the same period of harvest 10 years ago?
    - ◻ Yes
    - ◻ No
    - ◻ I don’t know

35. If No: What is influencing the changing crop calendar?

Soil Quality

36. Have you noticed changes in the following soil quality in the past 10 years?
    - ◻ No
    - ◻ Yes
    - ◻ I don’t know

37. If yes, please select all that applies to you:
    - ◻ Erosion
    - ◻ Fertility
    - ◻ Water retention
    - ◻ Acidity/pH
    - ◻ No changes
    - ◻ Other _______

38. What do you think might have caused this?

39. How did you notice these changes?

Yield

40. Has your yield changed over the past 10 years?
    - ◻ Yes
    - ◻ No
    - ◻ I don't know

41. If Yes: How would you explain these changes in crop productivity?

42. Have you changed your farming practices in the last 10 years? If you have, please select each that applies for you.
    - ◻ No
    - ◻ Crop diversification
    - ◻ Crop-rotation
    - ◻ Cover crops
    - ◻ Intercropping
    - ◻ Cultivar choice
    - ◻ Increase fertiliser
    - ◻ Decrease fertiliser
    - ◻ Organic farming
    - ◻ Conservation farming
    - ◻ Greenhouse
    - ◻ Precision farming
    - ◻ Irrigation
    - ◻ Drainage
    - ◻ Flower strips
    - ◻ No till
    - ◻ Agrotourism
    - ◻ Agroforestry
    - ◻ Other ____

43. Could you please describe the reason(s) for the overall changes in agricultural practices?

44. Have you received increased subsidies for managing your farm?
    - ◻ Yes
    - ◻ No

45. If Yes: Could you specify what you have invested in?

Contact

If you would like to be contacted with the report and potential soil data information, please state your contact information
Email _______
Phone number _______

Additional questions

What is the biggest challenge for your farm in the future?
(e.g. fertilizer costs, energy costs, price/income volatility, weather volatility or extreme weather events, crop protection costs)

Do you worry about the impact of the possible weather changes and weather events on your farm?

Appendix 3. NDVI Guide

Steps followed in order to conduct an NDVI analysis:

a. Creating the Świętokrzyskie voivodeship shapefile
    i. Downloading the Voivodeships shapefile at the Polish Government geoserver
    ii. Segment them in QGIS to get only the Świętokrzyskie voivodeship shapefile

b. Downloading the TIFF images
    i. Choose the timeline of focus: in this study June (month prior to harvesting with crops already grown)
    ii. Access to the USGS website and register
    iii. Add the Świętokrzyskie voivodeship shapefile to acquire the images
    iv. Apply the following filters:
        1. Landsat 2 images
        2. June 2013-2023
        3. Bands 4 and 5 (required for the NDVI formula)
        4. 0-50% clouds
    v. Select the images with minimal cloud cover that cover the entire voivodeship
    vi. Start downloading the images (TIFF), only Bands 4 and 5

c. Processing the TIFF images
    i. Open the images individually by years in QGIS
    ii. Make cuts of the TIFFs with higher cloud cover
    iii. Merge the cuts and cut them again with the Świętokrzyskie shapefile
    iv. Repeat this process for each band 4 and 5 of each year (2013, 2016, 2019, 2022 and 2023)
    v. Apply the following NDVI formula with the raster calculator tool: (B5-B4) / (B5+B4)
    vi. After getting the new TIF apply a pseudocolor monoband and assign the RdYlGn (red to green) band with 4 classes
    vii. Set the following values for each class:
        1. Red → < = 0.0
        2. Orange → 0.0 - 0.3

3. Light green → 0.3 - 0.5
4. Green → > - 0.5

d. Analysing the NDVI
   i. Visually compare the NDVI map for each year to observe changes in vegetation health over time
   ii. Use the histogram tool of QGIS to get the vegetation’s health values in a frequency distribution graph
   iii. Download the images and edit them in Photoshop one by one to get the same values for the X and Y axis for each of the frequency distribution graphs
   iv. Analyse and compare the graphs to have a more precise knowledge of the numeric values that represents the distribution of vegetation’s health in the voivodeship

e. Repeat the same process but for 2018 and 2020 images in april-may and august

Appendix 4. Observation Research Methods

The observation are categories by topic:

Animals:

- Chickens, hens, roosters, cows, sheeps, bees, goats





Machinery:

- Ploughing, sowing, irrigation, tractors, weeding, mowing, wood cutting, harvesting
- Most Machinery was adapted to lower scale production

Self-sustaining:

- Most farmers are making their own manure and natural fertiliser
    - Pile of fertiliser production was often observed on the farms/agricultural land
- Energy production
    - Most houses in the region had solar panels

Fields:

- A lot of wet flooded agricultural fields

- Strip agriculture (grass separating the fields): possible for biodiversity reasons or relating to the interaction of crops
- Fields dedicated to flowers: for commercial production, feeding bees, and biodiversity purposes
- Usually smaller strip-like fields but also large fields

Appendix 5. Soil Information Documents for Farmers (Template)

Dear participant

In exchange for your participation of answering our survey we have analysed your soil in the following parameters:

Soil texture	Mean pH	Water holding capacity	Organic carbon	Total nitrogen

Explanation of the parameters

Soil texture: Describes the content of sand, silt, and clay that your crop has.

pH: Indicates how acidic/basic your soil is ranging from 0-14. Depending on your crop you would ideally have a pH of 6-7. This point is where most of the nutritions in the soil is available for the crops.

Water holding capacity: Indicates how much water your soil can hold. A soil with high capacity holds water well in drought. A soil with low capacity will not hold water during a drought.

Organic Carbon: Indicates the amount of organic carbon stored in your soil. The carbon is energy for microorganisms in the soil, and also helps the soil particles to stick together. Therefore a high carbon level indicates a healthy soil.

Total Nitrogen: Indicates how much nitrogen is stored in your soil. The form the nitrogen is in may not be available to the plants. Nevertheless, it explains the potential nitrogen that the soil can supply throughout time.

Thank you for your help
Best regards

Elia, Genesis, Kondi, Alonso and Dina

Appendix 6. Synopsis

Introduction

Agricultural context

Agriculture plays a vital role in Poland, with approximately 60% of its territory considered arable land. Cereals, predominantly wheat, account for 69% of total production, followed by fodder (10%), potatoes (2%), and legumes and grains (3%). A significant portion of the population (12%) is engaged in agriculture (compared to the EU average of 5%).This is notably related to the structure of Polish agriculture, largely dominated by small family farms, with around 55% operating on less than 5 hectares of land(European Commission 2014). In Poland, more than 50% of the soil is clay-alluvial while 26% is sandy soil and other types of soil. The country has 1% of the very fertile soil chernozem, located in Świętokrzyskie (Koncewi-Baran & Świtek, 2021).

Agricultural activities in the Świętokrzyskie province follow the national trends. Sown areas are dominated by the production of cereals (wheat, rye, barley, oats, corn for grain, buckwheat, millet, and mixed cereals). Other crops include sugar beets, potatoes, turnip rape. The production is mostly carried out in large-scale farms, with 42,5% of agricultural holdings being from 2 to 5 ha (Statistical Office in Kielce, 2019). Between 2005 and 2018, there was a 2,53 % decrease in farmland in the province while an increase in farm size at the individual level was observed (Musial W. et al., 2020). Nearly 90% of agricultural lands are in good condition with 2,5% in fallow (GUS, 2020). Social and economic changes resulting from Poland's entrance into the EU affected the agricultural structure in the country; and the Świętokrzyskie province experienced the most significant transformation in Poland (Musial W. et al., 2020).

Climate context

Shifting weather patterns and occurrence of extreme weather events are becoming more prevalent across Europe. As outlined in the IPCC report, these changes are primarily attributed to human-induced climate change (*IPCC, 2023)*. In Poland, alterations in atmospheric circulation patterns and climate change are evident through the increasing and intensified trends observed in average annual and seasonal air temperatures and precipitation; and distinguishable in Poland's generally warmer and cloudier climate (Farlaz, 2021).

Since the mid-1900s, Poland has experienced a notable increase in its average temperature, rising by just over 2°C (Meteo IMGW-PIB, 2023) and (*IEA, 2022*); especially in the eastern and western regions of the country (UNFCCC, 2022). The level of warming in Poland largely surpasses the global average rise over the past decades. Precipitation in Poland is characterised by a strong variability in years, season and geography (UNFCCC, 2022), with climate projections suggesting that precipitation intensity will continue to rise across the country in the coming decades *(IEA, 2022).* Although there hasn't been significant shifts in annual precipitation trends since the mid-1950s, there has been a notable increase in extreme precipitation excess and extreme precipitation deficit (IEA, 2022; (Koncewi-Baran & Świtek, 2021; Pińskwar et al, 2018). South-Eastern Poland, known for its frequent and intense extreme weather events, is especially vulnerable to such occurrences (Kundzewicz, 2016). As the climate changes in Poland, the frequency and intensity of many extreme phenomena such as heat waves, floods, droughts, strong storms or hurricanes grow, affecting human health and life, the economy and the natural environment (UNFCCC, 2022).

Agriculture is heavily impacted by climatic conditions, particularly temperature increases and changes in precipitation and weather extremes like droughts, hurricanes, landslides and heavy rainfall. These climate conditions can negatively affect crop growth, soil moisture anomalies, and ultimately lead to crop failure and agricultural insecurities (Kundzewicz et al, 2018). Moving forward, this bears significant implications for Poland's future, as climate change-related hazards have the potential to impact as many as about 15 million Polish citizens (UNFCCC, 2022) The EU Regulation acknowledges the threat posed by climate change and has established a framework for achieving climate neutrality (Regulation 2021/1119). Poland has formulated the National Strategy for Adaptation to Climate Change (NAS 2020), outlining goals for the perspective of 2030, published in 2013 by the Ministry of the Environment.

Vulnerability and adaptive capacity

When considering Poland's present climate conditions, it is crucial to focus on the adaptation of agricultural systems to climate change. Adaptation to climate change entails the adjustment to prevailing or anticipated climatic conditions and associated impacts (FAO, n.d.). The concept of resilience, defined as the capability to adapt, transform, and reorganise, is pivotal to understanding the impact of climate change on agricultural systems, their productivity and capacity to cope with hazardous trends, events, or disturbances (IPCC, 2014). Shaping resilience, agricultural system's present different levels of vulnerability, "the predisposition to be adversely affected" (IPCC, 2014), which define the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change (FAO, n.d.). This vulnerability is commonly described as a function of exposure, sensitivity and adaptive capacity (Thomas et al, 2018). Practically, adaptive capacity embodies the capacity to devise and implement effective adaptation strategies to mitigate the detrimental outcomes stemming from climate-related hazards (Brooks and Adger, 2005). Adaptive capacities rely on the available resources and the system's ability to utilise them effectively. Nonetheless, external barriers, such as regulations, social norms, knowledge and culture, can impede on adaptive capacity (Brooks and Agder, 2005).

The focus on resilient adaptation takes point of departure from existing vulnerability theories, in order to examine Checiny's agricultural systems ability to cope with changing weather patterns and climate hazards. This research delves into the question of how resilient is agriculture in Chęciny to the impacts of climate change?

To answer explore this research question, sub-questions and hypothesis have been devised:

1.How have farmers perceived the changes in environmental conditions?

Hypothesis 1.1: The general experience is that environmental conditions has changed over the years

Hypothesis 1.2: Farmers perceive climate change as a future challenge and agricultural risk

2.How has climate change affected the productivity of agricultural production?

Hypothesis 2.1: Soil fertility and quality have declined

Hypothesis 2.2: The soil is not adapted to the new climate conditions

Hypothesis 2.3: Crop health has declined

Hypothesis 2.4: There is a decline in productivity due to environmental changes

3.How has the agricultural systems adapted to climate change in Chęciny

Hypothesis 4.1: Banks have increased their economic support to farmers

Hypothesis 4.2: New agricultural techniques have been introduced by farmers in response to climate change

Methodology

1. Experience of climate change

To explore farmers' perceptions of environmental conditions, surveys and short structured interviews will be employed. The choice of methods stems from consideration of potential language barriers and desire for unbiased analysis through predominantly qualitative analysis.

The survey will gather demographic information and explore perceptions of changing environmental conditions over the past decade, focusing on experiences with changes in weather patterns and extreme weather events over the last decade. Additionally, brief semi-structured interviews will delve into participants' views on future challenges and opportunities.

Additionally, brief structured interviews will delve into participants' views on future challenges and opportunities. Interviews are widely used among qualitative researchers to collect required data, and are considered important tools to extract data from participants (Elhami and Khoshnevisan, 2022). Interviews will be developed by the research group but conducted by a translator to enhance communication. Recorded interviews will be transcribed and translated using Microsoft 365 and reviewed for accuracy.

Given limited resources and time constraints, convenience sampling will be employed to select the participants of the survey and interviews; inquiring farmers directly on their farms in the area of interest. To encourage participation, farmers will receive incentives, including a report detailing their soil properties, the research findings regarding the impact of environmental conditions on agriculture and Danish candies as a token of appreciation.

Survey results will undergo quantitative analysis. Interviews will be analysed through a thematic qualitative analysis to understand participants' attitudes better.

2. Climate change effect on agricultural productivity

<u>Soil analysis</u>

Past soil data will be compared from the European soil database 'LUCAS' or previous studies with present soil data obtained through cluster soil sampling in the Chęciny area of Poland. A few strata per field from consenting surveyed farmers will be chosen to represent the population. For each cluster, 3 soil core samples, taken with a soil core sampling device will be composited, combined into one homogenous sample, in order to eliminate local variability and reduce analytical costs associated with analysis. Samples will be dried and sieved through a 2mm sieve before undergoing analysis in the laboratory.

The following soil properties will be measured (conditional on the soil data available on the European soil database and previous studies):

Soil texture

After adding water to the samples until uniformly moistened, they will be characterized in terms of texture using the finger method as described by Rowell (2014).

pH

A solution of dry soil:water 1:2,5 will be made for each sample. The samples will be shaken for an hour and left for 30 min before the pH is measured with a pH meter (Müller-Stöver, D., 2024)

Plant available phosphorus

Dry soil will be mixed with $NaHCO_3$ with pH of 8,5 in relation 1:20. The solution will be shaken for 30 min and filtered through a non-turbidity filter. Hereafter 1,5M sulphuric acid will be mixed with the solution in relation 1:5, and stored overnight under swirling. Lastly a flow injection analysis will be conducted to acquire the result (Müller-Stöver, D., 2024).

Water Holding Capacity

A tube will be filled with 5-7 cm soil and water. The tube will stay in a water bath for 24 hours and will be transferred to a tray with sand until constant weight is achieved. Hereafter it will be placed in a beaker and the wet-weight will be measured. The mass will be dried at 105°C, cooled in a desiccator, and reweighted. The water-holding capacity will be calculated using the following formula:

$$(ms-md)/(md-mt)\cdot 100=WHC(\% \text{ of dry mass})$$ (Müller-Stöver, D., 2024)

Additional method to be conducted under supervision:

- *Total C and N*
- *Cation Exchange Capacity: CEC*
- *Bulk density*

Normalize Difference Vegetation Index (NDVI)

To assess plant health and detect changes over time, an NDVI (Normalized Difference Vegetation Index) analysis will be conducted. Imagery from Landsat of July of each year, obtained from geodatabases like Copernicus or USGS, will be compared from the past 10 years. Examination of images following extreme weather events in the region will be considered, in order to draw conclusions on the effect of these weather events on crop health.

Surveys

Surveys will be conducted with farmers, in order to gather information on crop calendar, harvest, yield productivity, harvest, soil quality, economic profits and overall their perceptions on changes in weather affecting production. This methodology will be incorporated in the same survey as 1.

Structured Interviews with the Key informants from the Mayor office and the Agricultural centre will be conducted in order to collect information regarding the general perception of productivity in the region.

Methodological triangulation will be used to verify the validity of the results. Additionally the overall results will be used to establish a correlation with the changing weather patterns.

3. Assessing adaptation practices

In order to understand the adaptive measures undertaken by the agricultural system in Chęciny in response to climate change dynamics over the last decade, conducting survey and interview research methods is crucial. The research methods will involve executing structured interviews with key informants from a local bank, from Chęciny's mayor office and from the Agricultural Advice Center. The objective will be to determine existing financial support to help farmers implement new techniques or technology in order to adapt to a changing climate and agricultural adaptation trends in the area. A structured interview and survey with local farmers will also be conducted to gain more insight into the different adaptation strategies, technologies developed and engaged with. Finally, complementary observation methods involving farms pertaining to interviewed farmers will enable us to observe possible different practices, technologies which have been introduced.

Overall objective: How resilient is agriculture in Chęciny to the impacts of climate change?						
Research question	**Hypothesis**	**Variables of interest**	**Methods**	**Inputs**	**Output**	**Comments**
1. Climate change *How have farmers perceived changes in environmental conditions?*	The general experience is that environmental conditions have changed over the years	Experience of changes in climate conditions over the years: temperature, precipitation, length and intensity of the weather pattern Independent variable: Type of weather events (nominal) Dependent variable: Perceived/not perceived (dichotomous)	Survey Structured Interviews	Farmers Mayor Key Informant	Quantitative data analysis: descriptive statistics (mode) Qualitative data analysis	Surveys and interviews conducted in Polish and analyzed in English Consideration of farmers' willingness to be interviewed
	Farmers perceive climate change as a future challenge and agricultural risk	Perception of the vulnerability to climate change	Structured Interview	Farmers	Qualitative analysis	

2. Impact of climate change on productivity *How has climate change affected the productivity of agricultural production?*	Soil fertility and quality have declined	Variation in soil properties over the years: pH, Plant available P, Total C and N, CEC, water holding capacity, texture of soil, bulk density Independent variable: period of time. Past/present (dichotomous) Dependent variables: pH, Plant available P, Total C and N, CEC, water holding capacity, texture of soil, bulk density. (numerical)	Multiple methods of soil analysis	Soil samples Secondary data on soil properties in the region from the past from European soil database (Lucas) or previous research	Comparative statistical analysis (T-test) Visualization of soil properties' evolution	Conditional on availability of past research and data on soil If we are not able to have data points from the past, we will do descriptive statistics instead.
	The soil is not adapted to the new climate conditions	Description of soil properties: water holding capacity, texture of soil, bulk density,	Multiple methods of soil analysis	Laboratory material and soil	Establishment of soil adaptability to climate conditions	We will consider comparing soil quality/fertility between spatially close farms with different

		CEC, Total C, pH, Plant available P, Total C and N.				adaptation techniques, in order to draw some hypothesis on the impact of adaptation techniques on soil properties
	Crop health has declined	Crop health	NDVI analysis	NDVI imagery and satellite photo	Visual comparison Statistical comparison	Correlation of results through triangulation between crop health, yields variation and soil properties
	There is a decline in productivity due to environmental changes	Perception of productivity with relation to environmental conditions	Survey Structured Interview	Farmers Mayor and Agricultural Center Key Informants	Quantitative data analysis Descriptive statistics Qualitative data analysis	Consideration of farmers' willingness to be interviewed
3. Adaptation How has the agricultural systems adapted to climate change in *Chęciny's*	Banks have increased their economic support to farmers	Financial support for agricultural transitions	Structured interview	Bank Key Informant	Qualitative data analysis	
	New agricultural techniques have been introduced by farmers in response	Adaptation techniques (irrigation, greenhouse, pest management,	Survey Structured interview Observation methods	Farmers Mayor and Agricultural Center Key	Quantitative data analysis Descriptive statistics (mode)	Consideration of farmers' willingness to be interviewed

	to climate change	agrotourism), crop diversity, resilient plant varieties Independent variable: Practice (nominal) Dependent variable: introduction/ no introduction (dichotomous) Independent variable: perception of changing weather events (dichotomous)		Informant s	Inferential statistics (chi square) Qualitative data analysis	Conditional on the visibility of agricultural techniques Potential use of GIS to map out the landscape