Agronomy for Sustainable Development (2024) 44:37
https://doi.org/10.1007/s13593-024-00970-8

RESEARCH ARTICLE

Archetypes of climate change adaptation among large-scale arable farmers in southern Romania

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Accepted: 3 June 2024

Abstract

Effects of climate change and especially the associated climate variability require farmers to adjust to increasing frequencies of extreme events. In the agriculturally highly productive Romanian Plain, the frequency, intensity, and duration of heatwaves and drought have increased over the past 20 years. Although recent surveys revealed farmers' awareness of climate change and enumerated a number of farm adaptation measures in the Romanian context, a systems approach to adaptation that allows conclusions on farm vulnerability and adaptive capacity is missing. Here, we use archetypal analysis to elucidate and characterize for the first time the types of adaptation responses of arable farmers in southern Romania. We conducted semi-structured interviews with 30 farmers managing 51,500 ha located across the southern lowlands of Romania, selected for their diversity of management approaches. Farmers were asked about experienced climatic disturbances, crop production losses during the most extreme events over the past 5–10 years, and the adaptation measures they implemented over that period of time. In addition, structural characteristics of the farm were recorded. The adaptation measures were classified and mapped on the efficiency, substitution, and redesign gradient used to classify sustainability stages. Results revealed three archetypes of adaptation, consisting of measures at field and farm level ranging from predominantly efficiency-enhancing ones (e.g., crop choice and management and risk insurance) to complete farm redesign involving agrotechnical and financial management changes. Structural farm characteristics did not explain differences between farms in their association with one of the archetypes. Our approach and results show for the first time both the need for strengthening farmer-level support in one of Europe's key food production areas and the lessons that can be drawn from the outlier adaptation examples. Current European and national policies offer opportunities for farmer organizations in Romania to make these conclusions actionable.

Keywords Functional farm typology · Climate variability · Agro-ecology · Financial management · Farm practices · Archetype analysis

1 Introduction

In recent decades, changes in climate have caused impacts on natural and human systems on all continents, and it is widely acknowledged that this will have far-reaching effects on food systems (IPCC 2021). Warming of the climate is unequivocal, and in many regions, changes in precipitation or snow and ice melt are affecting water resources in terms of quantity and quality. These changes have predominantly negative impacts on crop yields (IPCC 2019). Using pre-industrial conditions (1850–1900) as a reference, data from the World Meteorological Organization show that Europe had its warmest year on record in 2020, and the top ten warmest years have occurred since 2000 (WMO 2021). Changes in extreme weather and climate events since the middle of the 20th century include increases in high and low temperature extremes and increases in the number of heavy precipitation events in several regions and in the number of consecutive days without rain in others. Hence, climate change has made extreme events more likely and more severe. Both wet and dry extremes are expected to become more likely, even in the same region. Almost everywhere

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Published online: 09 July 2024

in Europe, the observed shift towards drier summers is predicted to become more accentuated in the future, together with an overall increase in variability of rainfall (Christidis and Stott 2021). These phenomena have been referred to as an increase in climate variability, which poses a major challenge to agriculture.

The Pannonian region, which includes Romania, is expected to be the most negatively affected by the changing conditions for crop production, which renders East-European countries extremely vulnerable given the role that agriculture still plays in their national economies (Olesen et al. 2011; Berkhout et al. 2015; Lung and Hilden 2017). This study focuses on the southern lowlands of Romania, an area that includes the agriculturally most productive cropping region of the country. Romania has been facing an increase in the frequency, intensity, and duration of heatwaves (Croitoru and Piticar 2012), most pronounced in southern Romania, with an increase in frequency of extreme rainfall events, a decrease of snow cover in the cold season, and ever drier conditions in the warm season (Busuioc et al. 2016; Croitoru et al. 2016; Bojariu et al. 2021). Recent examples are the spring of 2020 when Romanian farmers faced a severe drought, with the country having its driest April on record (WMO 2021), and summer of 2022, which was exceptionally hot and dry (Fig. 1). These observations sustain the expected tendency of decreasing water reserves for agriculture, especially in the river basins of south and east Romania (Bojariu et al. 2021).

At farm level, climate variability is a source of recurrent disturbances of both environmental and market factors, threatening crop yields and farm income and therefore farm sustainability. The impact of poorly predictable climatic perturbations on crop yields and farm income can be mitigated by farmers through adaptation measures. These can take the form of crop production practices or financial management tools aimed at lowering the vulnerability and increasing the adaptive capacity of their socio-ecological systems (Smit and Skinner 2002; Gitz and Meybeck 2012; Groot et al. 2016). Vulnerability has been described as the predisposition of a system to be adversely affected. Adaptive capacity refers to the system's ability to adjust to perturbations caused by climate variability in order to moderate potential damages, cope with the consequences, and take advantage of possible opportunities (IPCC 2012). An effective adaptation response, as the combination of all the implemented measures, ensures continuity of the farm system and buffers crop production and farm income against the adverse impacts of increased climate variability.

To complement the limitations of large-scale adaptation approaches and to finetune measures to the highly localized nature of climate change potential impacts, the European Commission developed the European Adaptation Strategy (EC 2013) to empower Member States to design and implement appropriate policies. The recent Farm to Fork Strategy that is part of the Green Deal of the European Commission (EC 2020) recognizes the potential of agroecology as

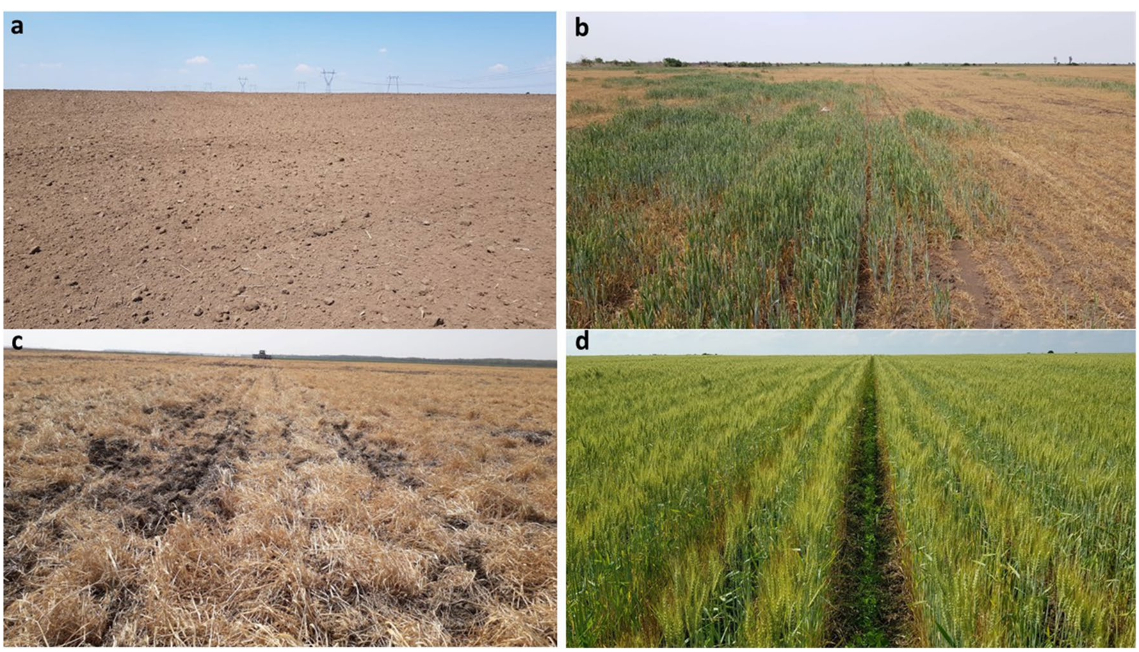

Fig. 1 Examples of tillage and crop cultivation approaches in southern Romania: **a** bare soil in spring, associated with intensive tillage, **b** consequences of drought on a sole wheat crop (spring 2020), **c** crop residues in a directly drilled field, and **d** wheat crop in relay intercropping system with soybean. Photos: Patrick Valmary.

a sustainable farming approach and emphasizes the need to promote and increase the use of agroecological practices and methods. The policy, when appropriately reflected at national level through the Local Adaptation Strategies (EC 2013), will provide a promising context for enhancing farmer support towards climate variability adaptation. Aguiar et al. (2018) presented an overview of 147 local adaptation strategies in Europe and analyzed sectors that were targeted, along with the triggers and barriers. The study included only one case from Romania, highlighting the need for more information on adaptation responses for Romanian farmers to support local and national decision making.

The aim of this research was to elucidate the types of adaptation responses of arable farmers in southern Romania facing increased climate variability and to draw inferences on the vulnerability and adaptive capacity of the farm systems. Recent studies described the uptake of individual adaptation measures by Romanian farmers (Petrescu-Mag et al. 2022; Micu et al. 2022). Here, we were interested in farm adaptation patterns, i.e., combinations of adaptation measures that are coherent to the farmer. Conceptually, this is equivalent to distinguishing functional farm types in functional typologies, described as “those that aim to capture decision making by farmers given their constraints, as well as their behavior in the face of climatic fluctuations or changing socio-economic situations” (Mettrick, 1993 in Tittonell et al. 2020). To elucidate such functional farm typology, we use archetypal analysis, a computational approach that identifies farm archetypes and constructs with the quintessential characteristics of the adaptation responses that are present in the empirical data. These archetypes are then used as starting points to identify farms with “membership” to these archetypes, i.e., to create clusters of farms with similar adaptation responses.

There are numerous possible adaptation responses that farmers can select from and tailor to their local particularities. Describing adaptation of farm systems towards greater sustainability, Hill and MacRae (1996) distinguished adaptation measures resulting in greater efficiency, in substitution of inferior practices by more sustainable ones, and in systems redesign. The resulting E(fficiency)-S(ubstitution)-R(edesign) framework has been used on numerous occasions to analyze transformation of farm and food systems (e.g., Gaitán-Cremaschi et al. 2020; Gliessman 2014; Tittonell 2014). In this paper, it enables assessment of the archetypes in terms of their adaptative capacity. The objective of this study, thus, is to identify farm archetypes based on farm adaptation responses to the increased frequency and severity of climate anomalies and shocks associated with climate change in southern Romania, to answer the question: What are the characteristics of the prevailing adaptation responses implemented by farmers in southern Romania and what do these characteristics imply about their vulnerability and adaptive capacity to climate variability? In the next sections, we introduce the study area, the analytical approaches, and the methods used for data gathering and analysis. We then present the adaptation archetypes and discuss them in terms of vulnerability and adaptive capacity. Using the archetypes, we classify the sampled farms using the ESR framework to elucidate the current level of climate variability adaptation as a basis for recommendations on farmers’ adaptation support.

2 Materials and methods

2.1 Study area

The study area is situated in the southern, extra-Carpathian lowlands of Romania, represented geographically by the Romanian Plain. The area is characterized by a humid continental climate (Dfa and Dfb climate types in the Köppen-Geiger classification system), with continental influences of aridity: large annual thermic amplitudes and low levels of precipitation, with winter frosts and frequent summer droughts. The annual average temperature is 10–11 ℃, and the annual rainfall is between 500 and 600 mm/year (Bogdan and Niculescu, 2006, as cited in Dumitraşcu et al. 2018).

In the past decade, the agricultural sector in the region faced pronounced weather anomalies, which have been attributed to increasing climate variability due to climate change. Changes in extreme temperatures have been observed in southern Romania in all seasons: more frequent and longer heat spells, but also decreasing frequency of frost days (Birsan et al. 2019; Bojariu et al. 2021). Analyzing the period 1990–2013, Prăvălie et al. (2020) found the combination of increased rates of evapotranspiration and heat spells caused significant yield losses in major crops. Over the past three decades, significant changes in phenophase and crop growing season start were observed (Bandoc et al. 2018). While on the positive side these changes mean that the growing season is longer than before, the projected climatic changes for 2050 show that the region will continue to suffer from increased incidence of heat waves and drought (Olesen et al. 2011; Micu et al. 2017). Predictions show that more frequent, shorter, and more intense precipitation events are expected in the lowlands of Romania, and the increased frequency of such extremes is expected even in areas with a trend of decreasing total precipitation (Harpa et al. 2019).

2.2 Analytical approaches

2.2.1 Archetype analysis

Farm typologies have been used for making sense of the diversity of farming systems (Tittonell et al. 2010; Righi et al. 2011; Alvarez et al. 2018; Riera et al. 2023). They may facilitate the selection of case study farms for detailed analyses and modeling or for scaling-up of field and farm level model results to regional level. Farm typologies may also be used for distinguishing patterns of more and less effective farm management, for tailoring or targeting interventions to a farm type or ensuring inclusive support measures. While there are isolated examples of methods that were used to derive farm typologies based on both structural and functional characteristics (Perrot 1990; Landais 1996), the majority of methods rely on grouping by structure (e.g., area and number of crops) and delineating groups of farms that are more similar to each other than to other farms. Based on dominant characteristics, each group is then labelled as a type.

Recently, archetype analysis has been proposed as an approach to create functional farm typologies and to identify patterns of adaptation measures, i.e., adaptation responses, across a diversity of farms facing a disturbance regime (Tittonell et al. 2020). The purpose of archetype analysis is not to classify all farms, but rather to identify archetypical farms, "which lie on the boundary of the data scatter and represent a sort of 'pure individual types', rather than typical observations or cluster centers." (Tessier et al. 2021). The approach is thus radically different from more commonly used methods such as principal component analysis, multiple correspondence analysis, or factor analysis combined with clustering, which identify clusters of farms with close-to-average characteristics. In contrast, the purpose of archetype analysis is to gain lessons from extremal cases, i.e., those that exhibit salient behavior or new strategies.

Archetype analysis is a statistical method based on unsupervised learning that iteratively identifies extremal points in multidimensional data. These extremal points are convex combinations of observations, i.e., linear combinations of the observations where the coefficients are positive and sum to one. The archetypes are thus extremal points of polygons that encapsulate the observations in the multidimensional data space. The archetypes do not necessarily represent real farms but should be regarded as quintessential farm cases that can be used as starting points to build clusters of real farms (Eisenack et al. 2019). The coefficients ("loadings") that emerge from the analysis are used to quantify the membership of a farm with an archetype. Farms may load fully onto one archetype that thus represents the farm completely or may have (low) loadings on various archetypes and thus remain unclassified. Farms with high loadings onto an archetype constitute examples of the essence of the archetype.

A practical advantage of archetypal analysis is that it may be used to build a typology with a relatively small sample size, without overlooking extremal but potentially informative cases in the sample as is a problem for conventional clustering methods (Tittonell et al. 2020). Recent applications of archetypal analysis addressed responses of households to drought in Argentina (Tittonell et al. 2020) and use of agroecological practices by beef farmers in Flanders, Belgium (Tessier et al. 2021).

2.2.2 ESR framework

There are multiple possible adaptation measures that farmers may tailor to local particularities. Describing adaptation of conventional (C) farming systems towards greater sustainability, Hill and MacRae (1996) coined the widely used (C) ESR framework distinguishing adaptation measures resulting in greater efficiency (E), in substitution of inferior practices by more sustainable ones (S), and in systems redesign (R). An adaptation measure focused on efficiency entails measures that reduce input and/or waste of environmentally costly and scarce resources, while one focused on substitution relies on replacing resource-dependent and environmentally disruptive products or procedures with more environmentally benign ones. Efficiency and substitution-oriented measures represent incremental adjustments typically within the logic of current production systems (Hill 1985; Pretty et al. 2018). It has been argued that the extent of adaptations needed to confront climate variability is such that more substantial, transformational measures need to be prioritized over incremental ones (Rickards and Howden 2012; Vermeulen et al. 2018; Zagaria et al. 2021, 2023). Measures involving ecological and economic diversification are considered to have the greatest adaptation potential (Vermeulen et al. 2012; Wezel et al. 2014; Nicholls and Altieri 2016; Waha et al. 2018; Rosa 2022). As ecological and economic diversification affect all components of a farm system, their uptake implies redesign of crop and financial farm management.

2.3 Data gathering and analysis

For data gathering and analysis, we used a combination of qualitative and quantitative methods to distinguish patterns of responses to climate change and to form a functional farm typology for the study region (Fig. 2).

Between April and June 2020, in-depth interviews were held with farm managers of 30 commercial arable farms in the Romanian Plain (Fig. 3). The farms were selected to represent divergent management approaches in the study region. Inclusion criterion was that the main activity was crop production. Farmer contact information was obtained from three local farm advisors and from a large farmer association.

Of the 30 farms, three were organic, four produced organically on a part of the arable area, further denoted as hybrid, and 23 produced using artificial fertilizers and pesticides. The number of different crops per farm ranged from three

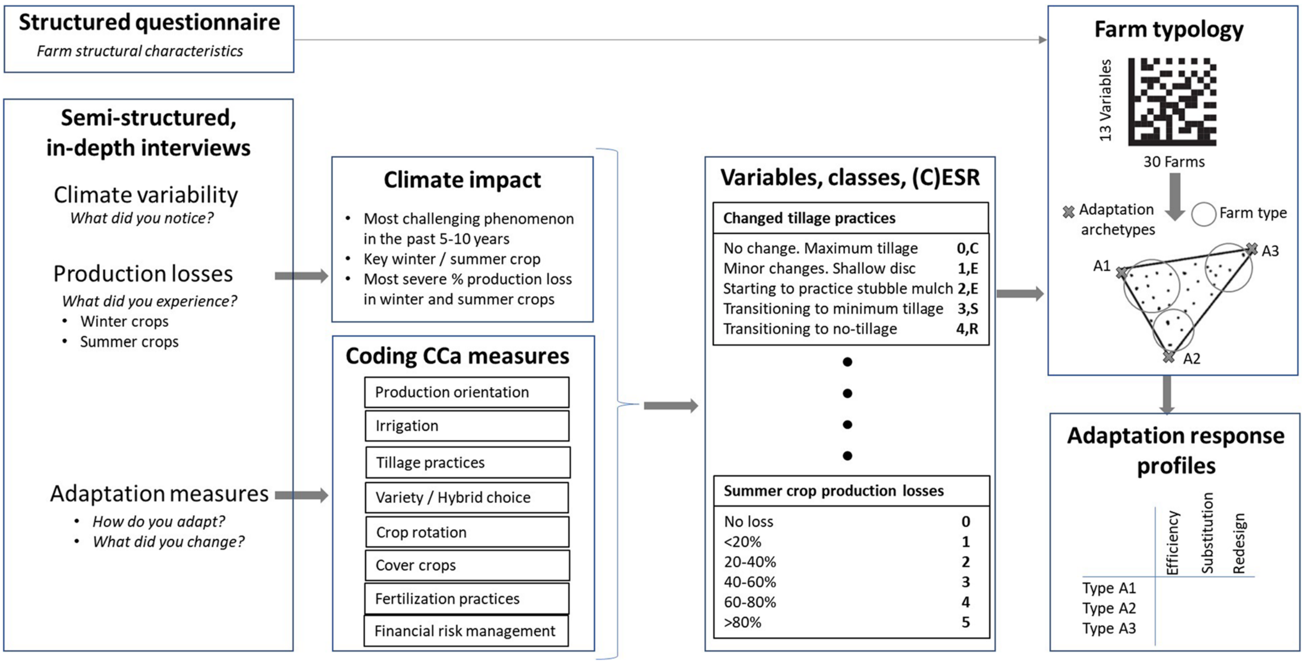

Fig. 2 Methodology used to develop the climate change adaptation (CCa) archetypes among large-scale arable farmers in southern Romania. A structured questionnaire and semi-structured in-depth interviews were used to identify variables to build the farm typology and to characterize the adaptation response of the farm types in terms of C (conventional), E (efficiency), S (substitution), R (redesign).

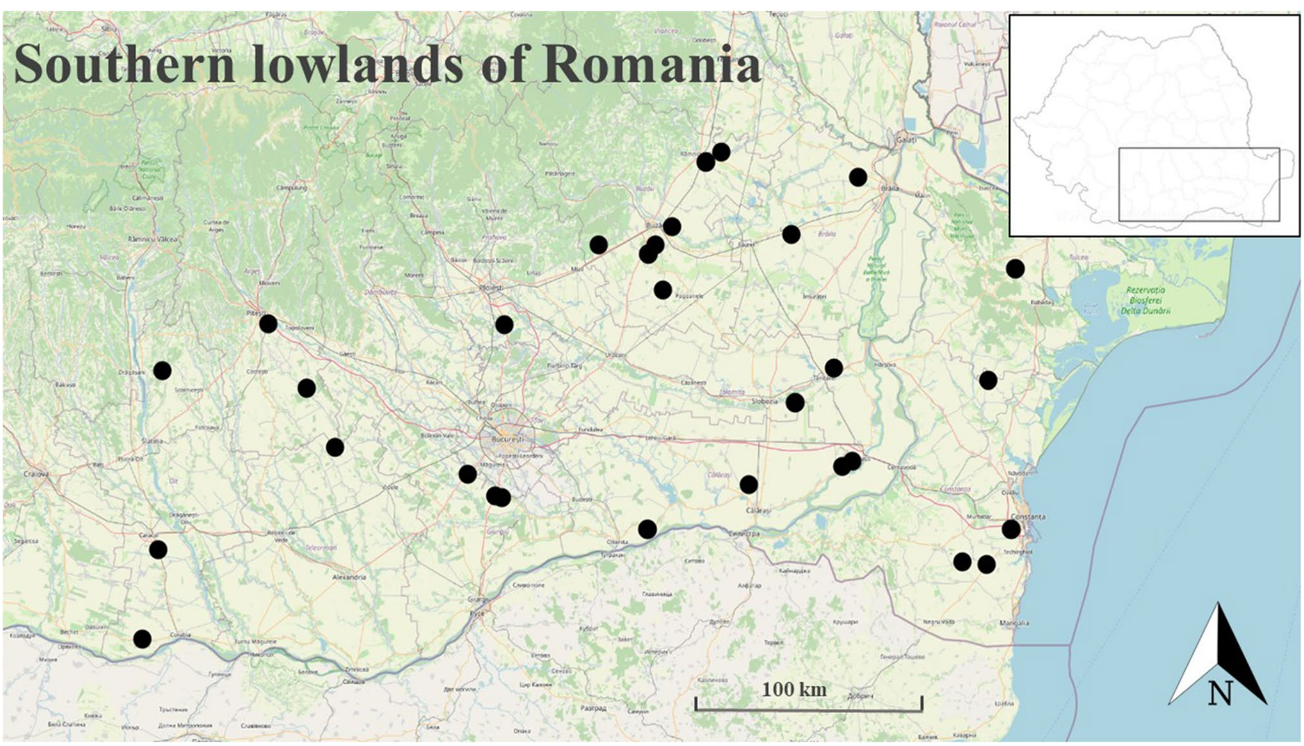

Fig. 3 Map of the study area in southern Romania. The markers indicate the farm locations of the interviewees included in the study (n = 30). Inset: location of the area on the map of Romania.

to ten, with 50% of farms producing up to six crops in relatively short rotations with crops such as winter wheat, winter barley, maize, sunflower, rapeseed, and 3–4 years of alfalfa. Five out of the 30 farms included livestock production. Farm sizes varied between 100 and 14,000 ha, with 75% of farm sizes below 2100 ha. Together, the 30 farms comprised an arable area of 51,500 ha.

First contact with the farmers was made by phone or, in some cases, by a farm visit. The aim of the study was explained as describing and analyzing the changes that south Romanian farmers have made on their farms in response to climate variability. Upon agreement to participate, an interview date was set and farmers were invited to provide information on farm structure variables, either through an online questionnaire prior to the interview or verbally at the start of the phone interview. The following farm structural information was recorded: farmer age, farm area, farm location, production orientation (conventional, organic, or hybrid), cultivated crops, and being associated with a farmers' organization. This step was followed by a semi-structured interview guided by an interview guideline. The guideline consisted of open-ended questions on experienced climatic disturbances, crop production losses during the most severe extreme events over the past 5–10 years, and the adaptation measures the farmer had taken to cope with or adapt to the increased frequency and severity of climate anomalies and extremes. The questions on adaptation measures were grouped into subtopics: farm area and history, livestock, farm income diversification, investments in farm infrastructure and machinery, product storage facilities, irrigation, tillage practices, crop pattern and rotation, soil organic cover, variety choice, genetic diversity, sowing and fertilization strategy, farmers' experiments, precision agriculture practices, sources of information on climate adaptation, farmers' cooperation, strategy for minimizing financial loss due to climate variability, forward contracts, and crop insurance.

The interviews in Romanian were recorded with farmer permission and fully transcribed, and the interview transcripts were coded with a focus on climate variability impacts on yield and adaptation measures. Coding was done by two of the authors. Most farmers gave several examples of climatic shocks in different years and their repercussions on crop yields. From these examples, we derived or selected the major loss per main crop per farm as a percentage of the yield during years with "normal" weather. We grouped the agronomic adaptation measures mentioned by the farmers into ordinal variables that represented themes. For instance, quitting plowing and starting non-inversion-tillage for winter crops and replacing disc harrowing in spring with shallower cultivation for summer crops were considered "changed tillage practices." For each variable, two or more response classes were distinguished that represented agronomically meaningful groups of the adaptation measures. Distinction of the themes and especially of the response classes proceeded iteratively by discussion among the authors until a degree of generality was obtained that expressed the essential differences, as is customary in archetypal analysis (Eisenack et al. 2019; Tittonell et al. 2020). The process resulted in a list of 11 themes, each with two or more response classes. Each response class was assigned a number to be used in the subsequent archetype analysis (Table 1). Finally, we classified each response class as belonging to one of the (C)ESR transition stages from conventional to sustainable agriculture (Table 1). Efficiency measures were considered to be those production practices within conventional technologies that reduced consumption and waste of costly and scarce resources, or those management tools or activities that did not require structural changes (e.g., making adjustments in fertilization practices). Substitution measures were considered to be those focused on the replacement of resource-dependent and environmentally disruptive products, techniques, or activities. In that sense, the transition to organic farming on only a part of the farm area was also considered a substitution measure. Redesign measures were considered those that addressed the root causes of problems by restructuring the farm with site and time-specific design and management approaches to decrease reliance on external inputs and on the influence of market forces.

We included two ordinal variables that described the size of production losses in winter and summer crops, respectively (Table 1), using the following scores: 0 (no loss), 1 (<20%; low), 2 (20–40%; low to moderate), 3 (40–60%; moderate), 4 (60–80%; moderate to high), and 5 (>80%; high). Each farm was thus characterized by ordinal scores for each of the 11 adaptation measures and by ordinal scores for the size of the production losses in winter and summer crops.

The 13 (variables) × 30 (farms) matrix was subjected to archetypal analysis following the approach used by Tittonell et al. (2020). Starting from one archetype, the number of archetypes was increased in stepwise fashion. The most appropriate number of archetypes describing the sample was determined using the second-order Corrected Akaike Information Criterion (AICc), suited for small sample sizes. The number of archetypes, or corner points of the multi-dimensional polygon enveloping the dataset, that was most supported by the data was identified by the lowest AICc value and ensured a balance between complexity and model fitness. The analysis was performed by means of the py_pcha module for Archetypal Analysis in Python (Jensen and Schinnerl 2017), using procedures similar to those described by Tittonell et al. (2020).

After identifying the optimum number of archetypes, the individual farms were assigned to a type using the two-thirds criterion (cf. Tittonell et al. 2020; Tessier et al. 2021): a farm was assigned to a type if the loading on an archetype exceeded 0.66. Decisions on the cut-off criterion

Table 1 Variables reflecting the salient adaptation measures against increased climate variability implemented by commercial arable farmers in southern lowlands of Romania and their production losses due to experienced climatic shocks. The adaptation measures are classified within the efficiency (E), substitution (S), or redesign (R) stages from conventional (C) to sustainable agriculture.

Variable	Class and description				Transition stage
Changed tillage practices	0	Maximum tillage-moldboard plowing, harrowing (dust mulching)			**C**
	1	Conventional tillage-shallow disking			**E**
	2	Improved conventional tillage; started stubble mulching			**E**
	3	Stubble mulch; started minimum tillage			**S**
	4	Minimum tillage; started no-tillage			**R**
Used cover crops	0	No			**C**
	1	Yes			**R**
Introduced new crops	0	No			**C**
	1	Yes, traditional annual legumes (peas and soybean)			**S**
	2	Yes, other annual niche legumes			**S**
	3	Yes, other niche crops			**S**
	4	Combinations (1 or 2, 3)			**R**
	5	Combinations (1, 2, 3)			**R**
Quit or reduced areas of affected crops	0	No, fairly constant cropping plan and/or few adjustments			**C**
	1	Yes, lowered frequency or area of certain crop(s)[2]			**E**
	2	Yes, quit cultivating certain crop(s)			**R**
	3	Combination (1, 2)			**R**
Cultivated drought-tolerant locally-bred winter wheat variety(ies)	0	Does not cultivate winter wheat			**C**
	1	No, only foreign varieties			**C**
	2	Yes, only locally-bred varieties			**S**
	3	Yes, in addition to foreign varieties			**R**
Made changes in fertilization practices	1	Yes, changed fertilization practices			**S**
	2	Few adjustments, almost no changes			**E**
	3	No changes at all			**C**
Set up irrigation system for cash crops	0	No			**C**
	1	No, but has taken steps for building it soon on a part of the farm area			**C**
	2	Yes, irrigation on a part of the farm			**E**
	3	Yes, and has taken steps for further expanding it			**E**
Transitioned to organic farming	0	No			**C**
	1	Yes, on a part of the conventional farm			**S**
	2	Yes, the entire farm			**R**
Purchased crop insurance	0	No, never			**C**
	1	Yes, sometimes and/or only for some crops			**E**
	2	Yes, always, all crops			**S**
Diversified farm income	0	No, only arable crop production			**C**
	1	Yes, livestock production			**E**
	2	Yes, crop processing for sale of value-added products			**S**
	3	Other ag-related activities using farm assets			**R**
	4	Commercial seed production			**R**
	5	Combination (1, 2 or 3)			**R**
	6	Combination (3, 4)			**R**
Used risk management tools against price volatility	0	No, sells almost entirely at harvest with spot contracts			**C**
	1	Yes, sells entirely at harvest and sometimes makes forward contracts			**E**
	2	Yes, sells entirely at harvest and always makes forward contracts			**E**
	3	Yes, stores a small part of the production and always makes forward contracts			**S**
	4	Yes, stores major part of the production and sells in off-season, the rest is sold at harvest through spot and/or forward transaction			**R**
	5	Yes, started contract farming, selling though short distribution chains			**R**
Winter crop production losses	0	No loss	3	40–60%	
	1	<20%	4	60–80%	
	2	20–40%	5	>80%	

Table 1 (continued)

Variable	Class and description				Transition stage
Summer crop production losses	0	No loss	3	40–60%	
	1	<20%	4	60–80%	
	2	20–40%	5	>80%	

are arbitrary: a lower cut-off value results in more farms to visualize an archetype but also in less distinctiveness of the archetype. Differences between the farm types in terms of structural characteristics farm area, age of the farmer, and associated with any type of farmer organization obtained from the structured questionnaire were evaluated with a Kruskal–Wallis test. The last step was the characterization of the archetypal responses based on the (C)ESR classification of the contained adaptation measures (Fig. 2).

3 Results and discussion

3.1 Climatic disturbances and adaptation measures

The in-depth interviews confirmed that drought was by far the most challenging phenomenon experienced by the farm managers of the 30 commercial arable farms in southern Romania over the past 5–10 years. Of the 30 farmers, 27 emphasized the increasingly frequent and severe drought events. Other phenomena mentioned by the farmers were related to greater temperature fluctuations: large temperature differences between day and night in spring and late frosts ($n = 18$) and scorching heat during pollination of summer crops ($n = 8$). When asked about the perceived anomalies in recent years, all farmers mentioned having noticed changes in precipitation patterns. They mentioned increased intra- and inter-annual variability ($n = 17$), more frequent torrential rain events ($n = 10$), and lack of precipitation in winter ($n = 13$). Difficulties due to water stagnation caused either by torrential rain or rising water tables were also pointed out ($n = 10$).

Farmers reported production losses over the past 5–10 years ranging from no loss to complete crop failure. Winter crops were reported to have had higher production losses (average score 3.4, range 0–5) compared to summer crops (average score 2.2, range 0–4). Winter wheat was reported as having the most severe losses by 24 out of 30 farmers, caused by the exceptional drought in southern Romania during the 2019–2020 cropping season right before and during the period in which the interviews were conducted. For summer crops, production losses in corn and sunflower were mentioned for 2010, 2012, and 2016–2020, but especially in 2019.

The adaptation responses of the farmers comprised a mix of changes in farm production practices and in farm financial management, aiming to mitigate the effects of the increased climate variability on both crop production and farm income (Fig. 4). Salient adaptations implemented by the farmers at field level included changes in tillage practices (73% of farmers in the sample), the inclusion of leguminous species (e.g., pea and soybean), and niche crops (e.g., high-oleic sunflower, linseed, mustard, or legumes: chickpea and lentil) in the conventional cash crop rotations (67%), the use of cover crops (60%), choosing to cultivate local varieties of major crops considered to be more adapted to drought (43%), abandoning the cultivation of sensitive crops, e.g., rapeseed (37%), or making changes in the fertilization strategy (30%).

At farm level, a large majority (80%) of farmers resorted to forward contracting and/or invested in storage facilities for off-season sales as risk management tools against price volatility, to even out fluctuations in their farm income due to weather anomalies. Forward contracts are preharvest agreements on price and delivery date for a part of the estimated production. Spot contracts on the other hand formalize sales of products with immediate delivery at the going market price. Purchasing crop insurance was part of the responses of 22 out of 30 farmers (73%) to mitigate weather-related risks. Another measure standing out as adaptation to climate variability was the farmers' engagement in other activities. Of the interviewed farmers, 60% had started activities beside crop production, either livestock production, crop processing into products with greater added value, or other commercial activities for farm income diversification (e.g., service provision with farm machinery or storage facilities). While irrigation was brought up in the interview by all 30 farmers as a key solution and opportunity for arable farming in increasingly dry conditions, 43% of them had no irrigation system. A transition to organic agriculture, whether completely or on a portion of the farm area, was adopted by 7 out of 30 farmers (23%). These farmers considered that the economic, political, and market factors around organic agriculture fostered stability of the farm business: first, production costs may be lower in organic due to lesser dependence on external inputs; second, because organic production received additional subsidies through CAP agri-environment schemes; third, because organic grains and oilseeds in high demand by local food processors or distributors and in low supply, allowing farmers more financial security by pre-contracting before sowing.

Our results on experienced climatic disturbances are consistent with earlier reports on crop production constraints

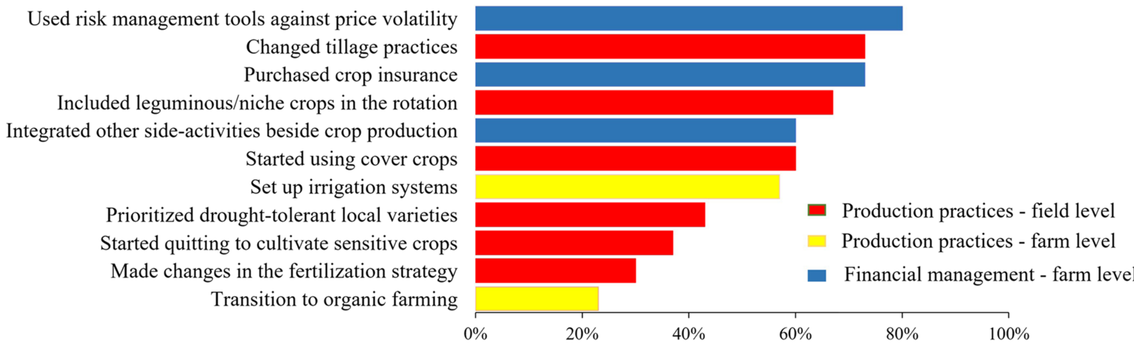

Fig. 4 Field and farm level adaptations that farmers implemented to buffer crop production and farm income against their most challenging phenomena of climate change. At each level, a distinction is made between production-oriented and financial management-oriented adaptations.

in the Pannonian region. Olesen et al. (2011) found that the occurrence of drought in this region was perceived by experts as the biggest limitation for winter wheat and corn production. The same study also reported changes in water-saving practices, introduction of new cultivars and crop species, erosion protection practices, and irrigation expansion, which corresponds with our findings. In contrast to the results of Olesen et al. (2011), the farmers in our study did not mention important shifts in sowing dates directly linked with the recent increase in climate variability. The responses on the topic of sowing strategy were highly diverse and showed a continuous, iterative adjustment of the timing of cultivation in the area depending on the crop and the specific conditions of each year. Melece and Shena (2020) document a similar set of adaptation measures for the Baltic Sea countries, including no tillage and minimum tillage, use of cover crops and mulches, crop diversification and rotation, adapted crop varieties, organic farming, and farm production and income diversification.

The results in Fig. 4 suggest that adaptation measures adopted by the interviewed farmers required capital, such as financial management practices involving storage capacity against price volatility, crop insurance, and the use of new tillage mechanization or cover crop seeds. Less adoption was found for agronomic practices that required detailed agro-ecological knowledge on, e.g., drought-tolerance of specific varieties, in some cases connected to quitting growing sensitive crops, or transition to organic farming. These results point to the need to enhance knowledge as part of climate change adaptation.

3.2 Archetypes of climate change adaptation responses

The lowest AICc value (207.17) was obtained at three archetypes, with >8 AICc unit differences to the next best solution and an R^2 of 0.81. Three archetypes thus ensured the maximum explanatory value of the model with the least number of parameters. Attributes of each archetype are shown in Table 2, expressed as rounded scores of the 13 variables describing adaptation measures and production losses. Applying the threshold of two-thirds (Tittonell et al. 2020; Tessier et al. 2021), 14 farms mapped fully onto one of the three adaptation archetypes (Table 3). The other 16 farms mapped weakly or not at all onto an archetype. Among the 14 farms, 5 farms (36%) mapped onto A1, 6 (43%) onto A2, and 3 (21%) onto A3. The three archetypes show that climate change adaptation in southern Romania involves changes both at field and farm level (Table 2 and Fig. 4). The adaptation archetypes reflected three overarching adaptation responses: irrigation for conventional commodity agriculture (archetype A1), transition to conservation agriculture and niche markets (archetype A2), and ecological and economic diversification (archetype A3). Their main features are described below.

A1. Irrigation for conventional commodity agriculture: additional water as the only way to survive

This is the archetypal adaptation response for conventional farms with short crop rotations around cash crops. The only marked adaptation measure consists of the implementation of irrigation infrastructure for a part of the cash crop area. Irrigation is typically used for summer crops only, as according to farmers the benefits for winter crops are insufficient. The scores of the remaining attributes of this archetype reflect well-established conventional practices: cereals and oilseeds in a short rotation, leaving the soil bare in between cash crops and maintaining the same fertilization practices as in the past. Tillage involves consistent use of the moldboard plow and the disc harrow for soil cultivation. Financial risks are managed by forward contracting. There were no organic farmers represented in this archetype. This archetypal adaptation response was associated with high production losses of winter crops and low to moderate production losses of summer crops.

A2. Transition to conservation agriculture and niche markets: minimum tillage as a necessary change

A key adaptation measure of this archetype is a change in tillage practices, in particular, the adoption of minimum-tillage systems with non-inversion tillage techniques and stubble mulching to reduce soil water loss. The moldboard plough is largely substituted with implements that work the soil vertically. The rotation is conventional grain-based, and niche grain legume species such as chickpea are introduced. The latter is a measure that exploits a market opportunity with a crop that is suitable for dry environments. Financial risks are not addressed specifically, as the only income source is crop production sold entirely at harvest with spot contracts. This archetypal adaptation response is associated with moderate to high production losses of winter crops and with moderate production losses of summer crops.

A3. Ecological and economic diversification: diversification as the way to go forth

This archetypal adaptation response is centered around diversification at both field and farm level, along with a complete change from conventional tillage to a no-till system. The crop rotation is diversified by introducing leguminous species, both traditional crops for the area (e.g., peas and soybean) and niche legumes (e.g., chickpea and lentils), together with other niche crops of higher unit value (vegetables and special varieties of cash crops). The use of multi-species mixtures for cover cropping is another feature of this response. Other changes in the crop rotation involve quitting to cultivate the crops that consistently performed poorly. Farm-level adaptations involve diversification of income sources through livestock integration and either crop processing or service provisioning to other farmers or companies (contract work and crop storage). Crop margins are increased by storing a major part of the production to sell in the off-season and by contracting the remainder depending on the market, be it through spot or forward contracts. This archetypal adaptation response is connected with low to moderate production losses of winter and summer crops.

3.3 Addressing climatic challenges at field level

Regarding the changes in tillage practices, archetype A1 maintained conventional practices, while archetypes A2 and A3 were characterized by the implementation of minimum tillage techniques, with A3 showing a start of the implementation of no-tillage systems. Reducing the intensity of soil tillage has been proved to have beneficial effects on soil properties promoting, among others, water retention and water use efficiency (Li et al. 2020; Nunes et al. 2020a). Intensive tillage enhances breakdown of soil organic matter as a result of accelerated oxidation and decomposition, enhances soil erosion, and ultimately leads to higher production costs (Verma 2021). Conservation tillage systems, such as minimum tillage and no-tillage, help restore and maintain soil fertility in the upper soil layer and reduce soil erosion by promoting organic matter accumulation and mineralization (Corsi and Muminjanov 2019; Nunes et al 2020b). The observed progression of changes in tillage from A1 to A2 and A3 reflects the empirical observation that minimum tillage is a necessary intermediate stage in the transition from conventional tillage towards no-till systems. The use of cover cropping as an adaptation practice closely followed the changes in tillage practices across the three archetypes, with A1 resembling the current conventional systems with low use of cover crops and A2 and especially A3 making substantial use of cover crops as is promoted in conservation agriculture. While establishment of cover crops due to dry conditions at sowing and the competition for water with the main crops constitute important tactical decision problems, cover crops can contribute to the strategic accumulation of soil organic carbon as the basis for soil fertility (Seitz et al. 2022) and are important tools for reducing the need for synthetic fertilizers and pesticides (Murrell et al. 2020). Furthermore, the use of multi-species mixtures with functional complementarity has been reported to increase the beneficial effects of cover crops (Chapagain et al. 2020).

Among the three archetypal responses, A3 revealed clear diversification of the conventional cereal-based rotations. Crop diversification has been shown to increase the resilience of farms in face of climatic shocks, being both a financial risk spreading strategy and an agroecological practice with agronomic benefits (Nicholls and Altieri 2016). Both archetypes A2 and particularly A3 had introduced leguminous species in recent years while reducing areas of crops that were regularly affected by weather vagaries. Leguminous species can reduce the farmers' dependence on external fertilizer sources by biological nitrogen fixation (Rodriguez et al. 2020). Both A2 and A3 involved the introduction of niche crops (variable "Introduced new crops"). Diversification with new crops for niche markets could increase the economic resilience of farms in face of the high price volatility of commodity crops and could potentially bring higher profit margins to farmers (de Roest et al. 2018).

Quitting to cultivate certain crops was characteristic to A3 showing again a higher degree of adaptability to climate change than A1, which perpetuated the status-quo. Rapeseed was the most frequently mentioned crop to have been abandoned in recent years due to more severe water scarcity around autumn sowing (mid-August to early September).

Another field-level measure that differentiated farmers' responses was the choice of varieties for winter wheat, a

Table 2 Structural features and attributes characterizing the three climate change adaptation archetypes (A1, A2, and A3) among crop farmers in southern Romania (loading > 0.66). For each archetype, farm structural features are presented as ranges or means. Attributes include field and farm level adaptation responses (coded in shades of green) and production losses (coded in shades of red). The attributes are expressed as rounded average scores per variable (see Table 1) and classified as conventional (C), efficiency (E), substitution (S), or redesign (R) measures. Score ranges are given between parentheses.

Farm structural features			
Average farm area (ha)	425	509	893
Range of farm area (ha)	100-1100	345-800	178-1800
Average farmer age	42	36	44
Membership of a farmers' organization (0-No, 1-Yes)	0.6	0.5	0.7
Field level adaptation measures			
Changed tillage practices (0-4)	**C**(0)	**S**(3)	**R**(4)
Used cover crops (0-1)	**C**(0)	**R**(1)	**R**(1)
Introduced new crops (0-5)	**C**(0)	**S**(2)	**R**(4-5)
Quit or reduced areas of affected crops (0-3)	**C-E**(0-1)	**E-R**(1-2)	**R**(2)
Cultivated drought-tolerant locally-bred winter wheat variety(ies) (0-3)	**S**(2)	**C**(1)	**S**(2)
Made changes in fertilization practices (3-1)	**C**(3)	**E**(2)	**E**(2)
Farm level adaptation measures			
Set up irrigation system for cash crops (0-3)	**E**(2)	**C**(0)	**C**(0)
Transitioned to organic farming (0-2)	**C**(0)	**C-S**(0-1)	**C-S**(0-1)
Purchased crop insurance (0-2)	**E**(1)	**E**(1)	**E-S**(1-2)
Diversified farm income (0-6)	**E**(1)	**C**(0)	**R**(5)
Used risk management tools against price volatility (0-4)	**E**(2)	**C**(0)	**R**(4)
Production losses			
Winter crop production losses (0-5)	5	4	1-2
Summer crop production losses (0-5)	1-2	3	2

Conventional Efficiency Substitution Redesign

Low Medium High

major crop for southern Romania. Archetypes A1 and A3 reflected a preference towards locally-bred varieties, whereas A2 tended towards using seeds of foreign varieties. The interviewed farmers cultivating only local cultivars considered them to be most robust in face of drought, while the farmers cultivating only foreign varieties stressed their superior yield. Local research confirms both viewpoints. Two years of experiments in the study area documented the higher yields of winter wheat hybrids compared to common local varieties (Guță et al. 2015), while Băcanu et al. (2018) showed that Romanian farmers preferred varieties bred by the Romanian National Research Institute in Fundulea, such as the cultivar Glosa, because of their greater yield stability compared to imported varieties. Local varieties with a long history of cultivation in a certain geographical area can be more resistant to the climatic challenges that are specific to that area, as these were part of the selective factors in the breeding process (Almekinders 2011; Almekinders et al. 2021). Under conditions of prevailing droughts in Romania, varieties with long-term stability and good production capacity may be more suited than varieties with exceptional yield but with high sensitivity to drought. On-farm and on-station experiments and local knowledge sharing for locally fitted solutions are needed to arrive at more detailed insights in the trade-off. An underexposed option is to cultivate both cultivar types as a risk-spreading strategy. While mentioned by several respondents in the interviews, it did not emerge as a major feature of any of the identified archetypal adaptation responses.

Several farmers mentioned changes in fertilization strategy that were prompted by changing weather patterns. Foliar application had been taken up in response to both water scarcity and torrential rains limiting uptake or availability of plant nutrients from traditional fertilizers. The archetypal

Table 3 Loading of the individual farms onto each adaptation archetype and farm characteristics (production orientation, farmer age, farm area, and membership of a farmers' organization). Shading indicates loadings of 0–0.33 (no shading), 0.34–0.66 (partial loading - light gray), 0.67–1.00 (full loading - dark gray). Missing data are indicated with an asterisk.

Farm	Production orientation	Farmer age	Farm area (ha)	Member of a farmers' organization	A1	A2	A3
1	Conventional	24	100	No	0.63	0.37	0.00
2	Conventional	49	2200	No	0.53	0.00	0.47
3	Conventional	27	300	Yes	1.00	0.00	0.00
4	Conventional	28	2230	Yes	0.47	0.00	0.53
5	Conventional	28	420	No	0.26	0.74	0.00
6	Conventional	24	430	No	0.49	0.51	0.00
7	Conventional	60	225	Yes	0.98	0.02	0.00
8	Conventional	24	100	Yes	0.74	0.08	0.18
9	Conventional	53	1100	No	0.68	0.00	0.32
10	Conventional	42	750	Yes	0.49	0.51	0.00
11	Conventional	62	1000	Yes	0.46	0.26	0.28
12	Conventional	34	620	Yes	0.00	0.80	0.20
13	Conventional	58	2760	No	0.47	0.00	0.53
14	Conventional	47	401	No	0.80	0.20	0.00
15	Conventional	27	700	Yes	0.00	0.25	0.75
16	Conventional	32	4000	Yes	0.35	0.11	0.53
17	Conventional	39	14000	Yes	0.38	0.00	0.62
18	Conventional	32	7000	*	0.44	0.10	0.46
19	Conventional	37	800	*	0.58	0.00	0.42
20	Conventional	55	370	No	0.00	0.90	0.10
21	Hybrid	30	2100	Yes	0.60	0.00	0.40
22	Organic	52	178	No	0.00	0.24	0.76
23	Hybrid	37	1400	Yes	0.48	0.36	0.16
24	Organic	32	700	Yes	0.00	0.61	0.39
25	Conventional	32	800	Yes	0.00	1.00	0.00
26	Hybrid	29	500	Yes	0.00	1.00	0.00
27	Conventional	35	3000	Yes	0.60	0.00	0.40
28	Conventional	52	1800	Yes	0.00	0.00	1.00
29	Hybrid	35	345	No	0.12	0.88	0.00
30	Organic	25	1200	*	0.57	0.01	0.42

analysis showed, however, that none of the adaptation archetypes was characterized by considerable change in fertilization strategy in the last 5–10 years (Table 3). The few adjustments for A2 and A3 may be connected to the major changes in the tillage systems that define these archetypes.

3.4 Addressing climatic challenges at farm level

Implementing irrigation on the farm was mostly a feature of archetype A1, which exhibited most characteristics of conventional farming strategies (Table 3). While costly, irrigation constitutes an adaptation option that allows continuation of prevailing practices without the need for major redesign. Archetypes A2 and A3 maintained rainfed production practices. Reasons may have been pragmatic: installing irrigation facilities comes at high investment costs and associated risks since often land is rented and, legally, leases can be canceled at short notice. Public irrigation infrastructure is lacking. Irrigation systems in the southern lowlands in Romania were built before the 1990s and today are largely degraded (Sima et al. 2015). A recent report describes non-functioning or inefficient infrastructure in more than 75% of the equipped area (EO Clinic 2021).

Crop insurance was used by all archetypes and most by A3, but apparently, occasionally and/or only for some crops as witnessed by scores ranging from 0.23 to 1.61 out of 3 (Table 3).

From our interviews, the farmers who had made the transition to organic farming also revealed several other adaptation measures at farm and field level. Other studies have documented the conversion to these low-input systems as a means to increase farm adaptive capacity (Bouttes et al. 2019). In the interviews, transition to organic farming was more frequently mentioned in relation to obtaining higher profits, as organic agriculture in Romania benefits from higher subsidies and product prices. In addition, farming organically meant lower exposure of farmers to the risk of financial loss in case of drought-induced crop failure, as the cost of crop production was perceived to be lower with organic low-input technology. Transition to organic showed up in archetypes A2 and A3, likely because organic production in Romania is allowed on designated parts of conventional farms rather than having to convert the entire farm to organic. Archetype A1, however, never utilized transitioning to organic farming as an adaptation measure.

Farm income diversification and price risk management tools were present in archetype A1 and particularly in A3. Income and market diversification in A3 was associated at field level with crop diversification. The combination of field and farm level measures may have been a result of an overarching diversification strategy (Darnhofer 2021) or may have been prompted by diversification requiring adjustments in other components of the farm system, for instance, to free up labor. Elements of income diversification at farm level included the integration of livestock, the beginning of on-farm crop processing as well as providing services to other farmers or companies allowing more productive use of on-farm machinery and time through contractor work, and providing crop storage space. While economic diversification implies higher workload per farm, it represents an orientation towards increasing the profitability of the business by better utilizing the labor and capital resources.

The use of price risk management tools was absent from archetype A2, which involved forward contracting in archetype A1, while archetype A3 used a diverse portfolio of price risk measures. Relying on forward selling as in A1 may lead to net financial loss when yields are lower than the volumes to which farmers committed and the product has to be sourced outside the farm (Roussy et al. 2018). The A3 response may provide more buffer by selling mostly in the off-season when offering the highest prices and contracting the production sold at harvest time depending on the market conditions with a combination of forward and spot contracts. While this response has the highest adaptive capacity to market fluctuations caused by increased climate variability, it is accessible only to farmers with sufficient financial resources to create and maintain enough storage capacity and whose production volumes ensure them negotiating power on the market.

Kruskal–Wallis tests did not reveal significant differences between the archetypes in terms of farmer age, farm area, and being associated with a farmers' organization (p value > 0.05, Table 3). This suggests that structural characteristics of the farms did not explain their functional responses, emphasizing the relevance of the farmer rather than the farm's characteristics. The spatial distribution of farms showed no pattern across the study area, except the A1 type of farms, which appeared clustered. However, the numbers are too low to draw any conclusions.

3.5 Vulnerability and adaptive capacity to climate variability of south Romanian farms

In this section, we map the three archetypes onto the transition stages from conventional to sustainable agriculture (efficiency – substitution – redesign) and assess the relation with vulnerability and adaptive capacity to climate variability.

Responses at field and farm level to climatic variability by archetype 1 involved predominantly no changes or efficiency responses, with only some uptake of drought-tolerant locally-bred winter wheat varieties qualifying as substitution response (Table 2 and Fig. 5). Compared to some uptake of efficiency adjustments in financial management, crop production measures were similar to those 10 years ago. The central feature of the A1 adaptation response, a transition from rainfed to irrigated farming, is meant to increase the efficiency of land and other resources (e.g., agricultural inputs), to eliminate the problem of recurring droughts by technologically controlling water supply as the major limiting factor of crop production in the region. An interviewed farmer embracing this perspective put it this way: "Irrigation is the only way to survive from now on, or otherwise we work in vain." While reducing vulnerability of farms to major summer crop production losses in the recent past (Table 2), winter crop losses could not be avoided as irrigation costs of those crops cannot be recovered. In addition, the impact of other climatic disturbances besides drought, such as scorching heat leading to pollen sterility, cannot be averted by irrigation (Begcy et al. 2019). This leaves A1 farms with a considerable degree of vulnerability to climate variability. Efficiency and substitution approaches are believed to be insufficient to ensure the sustainability of farm systems in future climate scenarios. In fact, they perpetuate the cause of the problem, the "maldesigned" (Hill 1985) malfunctioning agroecosystem (Fig. 5). Archetype A1 thus revealed the least adaptive capacity of the archetypes.

Responses of archetype A2 involved measures mainly focused on efficiency and substitution, with some redesign measures at field level (Table 2 and Fig. 5). The measures at

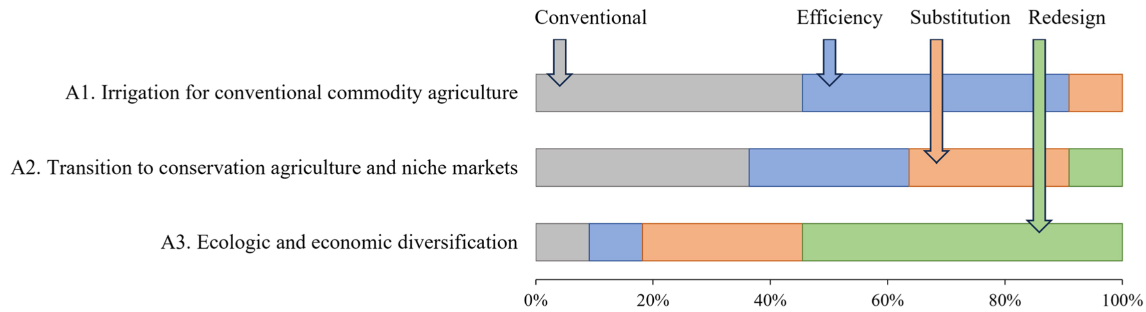

Fig. 5 Adaptation archetypes A1 to A3 in the southern lowlands of Romania and the relative frequency of adaptation measures classified within the framework of Conventional – Efficiency – Substitution – Redesign (from left to right in each bar).

field level may be grouped as soil conservation measures that are also promoted under the header of conservation agriculture (CA): reduced soil disturbance, permanent soil cover, and crop diversification. The redesign of soil management may well stimulate subsequent more radical changes at field level (Darnhofer 2021). Financial adaptation measures were largely absent in this archetype, with the exception of some farms having crop insurances, a measure which was also present in the other archetypes. Production losses in archetype 2 were medium to high. These may be indicative of the need for a broader set of adaptation measures, or the need for better implementation of the measures.

Archetype 3 revealed adaptation through ecological and economic diversification in response to climate change in southern Romania. This entailed the full diversity of agroecological adaptation practices at field level, and risk management tools focused on redesign of the farm system (Table 2 and Fig. 5). The implementation of no-tillage, the use of cover crops and longer rotations including new and nitrogen-fixing species, and the abandonment of severely affected traditional crops are complex measures that address multiple components of the agroecosystem. In addition, these field level adaptation measures were supported by all categories of farm level adaptation measures, interestingly with the exception of uptake of irrigation. We categorized slightly over 50% of the adaptation measures as redesign measures (Fig. 5). These occurred in conjunction with efficiency and substitution measures, indicative of the re-balancing (*sensu* Verhoeven et al. 2003) involved in adaptation to increased climate variability in southern Romania. The fact that archetype A3 was associated with low to moderate crop production losses of winter and summer crops, respectively, supports the hypothesis that this response strategy has the highest potential to ensure resilience of the farm systems in southern Romania in the face of climate change.

Donham et al. (2022) used the efficiency-substitution-redesign classification in their recommendations for more effective Eco-schemes as part of the 2023-2027 Common Agricultural Policy of the European Union. In line with our findings, they emphasize the need to combine (and reward) several coherent agroecological adaptation measures in one eco-scheme and point to the efficacy of redesign practices over efficiency and substitution practices. In contrast to our results, however, they do not address financial management measures explicitly.

3.6 Consequences for support of climate change adaptation in Romania

The results highlight that structural adjustments at both field and farm level are as yet lacking in the majority of farms on the Romanian Plain, as witnessed by the dominance of adaptation archetypes A1 and A2. Clear structural (i.e., redesign) adjustments at both field and farm level are only apparent in archetype A3. Other studies found wide-spread climate change awareness in Romania (Cheval et al. 2022; Petrescu-Mag et al. 2022), also among farmers. While awareness constitutes a necessary condition for a transformative change in practices (Horner et al. 2021), enactment requires additional factors such as farmers' ability and willingness and the opportunity to experiment (Prager and Posthumus 2010).

Our findings did not show a significant effect on uptake of climate change adaptation measures of farmers' age (p = 0.97), farm area (p = 0.44), or of being associated with a farmers' organization (p = 0.30, Table 3). A World Bank review (Tebaldi and Gobjila 2018) identified a lack of effective extension services for agriculture in Romania and recommended better integration of knowledge flows from consultancy, agricultural research, and agricultural education. Hence, there is much-unused potential for farmers' organizations in Romania to become engaged in supporting farmers to develop effective adaptation strategies, supported by appropriate policies. Such changes will meet with political, socio-economic, and cultural lock-ins as described by Hălbac-Cotoară-Zamfir et al. (2019). The farms resembling adaptation archetype A3 may act as inspiring outliers, which, similar to positive deviants (e.g. Modernel et al. 2018; Adelhart Toorop et al. 2020), demonstrate good practices and performance and may show how technical and social barriers were overcome during the farms' redesigns. Similarly, studying farms resembling types A1 and A2 may reveal which barriers hinder them from improving their current condition. Such knowledge will contribute to unfolding the potential of agroecology, which was identified by the European Commission (EC 2020) as a way out of malfunctioning current agroecosystems, and defining appropriate local adaptation strategies at national level.

3.7 Methodological considerations

The farm typology based on the adaptation archetypes allocated 14 farms to three farm types, according to the chosen threshold of two-thirds loading (Table 3). Among the 14 farms, there were 6 farms with full loading on A2 and 5 farms on A1. Three farms fully mapped onto A3. The other 16 farms did not have a similarly strong membership to a single archetype. We note that even if archetype A2 had the highest representation in our sample of farms followed by A1 and A3, the relative share of the different farm types in Romania should be studied with a census.

The farms were selected through intermediaries and with the purpose of representing variation in management. The 30 farms were well spread across the Romanian Plain (Fig. 3), and over the course of the 30 in-depth interviews, we noted increasingly fewer instances of new adaptation measures, suggesting data saturation (see e.g. Saunders et al. 2018). There are thus grounds for the assumption that the typology presented here covers the major adaptation response patterns of crop farmers in the study region.

In a recent study, Petrescu-Mag et al. (2022) collected structured questionnaire data from 316 randomly sampled farmer respondents at Romanian national level to elicit climate consciousness. They found greater percentages of uptake of measures in response to perceived climate change than in our study, e.g., "Introduction of new crops/varieties (not GMOs)" was mentioned by 92% of the respondents, "Introduction/extension of crop rotation" by 91%, and "Modification of the sowing season" by 89%. A study by Micu et al. (2022) at national level based on 407 structured questionnaires applied by snowball sampling found lower uptake percentages than in our study even though awareness of climate change variability among respondents was high. Reasons for the differences with our results include the nature of data collection and the geographical resolution of the studies. The structured questionnaires with predefined categories and yes/no answers may have resulted greater socially desirable answers (Vesely and Klöckner 2020) compared to the semi-structured interview approach in this study. Furthermore, aggregating survey results at the national scale does not do justice to the high spatial variability of the increased drought frequencies due to climatic variability (e.g., Birsan et al. 2019; Prăvălie et al. 2020 for maize).

4 Conclusion

This study revealed that by using the full diversity of agroecological practices at field level together with risk management tools, all focused on redesign of the farm system, farmers can respond effectively to the impact of increased climate variability in the southern Romanian lowlands. We showed that ecological and economic diversification is the adaptation archetype with the highest potential to ensure resilience of the farm systems in southern Romania in the face of climate change. The large majority of farmers in Romania (Petrescu-Mag et al. 2022) acknowledge the existence of climate change in the country. In our sample, we found 10% of farms to have implemented systemic adaptations in field and farm management.

Our approach and results show both the need for strengthening farmer-level support and the lessons that can be drawn from the A3 archetypes. Interestingly, structural variables (e.g., farm area and farmer age) were not significantly different across archetypes, indicating that adaptation to climate change may not be dependent on structural characteristics of farms. Efficient adaptation to climate change may be within the reach of all types of arable farms, and policy design aimed at fostering their adaptive capacity should focus on functional differences (e.g., logics or farming rationale) instead of, for example, farm size.

This is the first comprehensive study on farmers' adaptation responses to increased climate variability in Romania that addresses both agrotechnical and economic dimensions of farms using methodological tools from social sciences. Identifying, analyzing, and better understanding farmers' current adaptation patterns in the face of climate variability will support effective policies that allow farmers to embark on broadscale sustainable development trajectories.

Acknowledgements This study was made possible with the help and support from AIDER association, through Anca Moiceanu, from Adrian Constantin Stoica (ECOCERT Romania) and two anonymous farm advisors. The collaboration of all farmers and their openness during interviews are gratefully acknowledged, as well as the contribution of Carl Timler for the help in the conceptualization phase of this research.

Authors' contributions Conceptualization and Methodology, C.N. and W.A.H.R.; Investigation and Data Curation, C.N.; Formal analysis, C.N and M.H.E.; Writing – Original Draft, C.N.; Writing –Review & Editing, W.A.H.R. and M.H.E.; Project administration, C.N.; Funding Acquisition, W.A.H.R.

Funding This study has received funding from the European Union's Horizon 2020 research and innovation program under grant agreements

No. 727482 (DiverIMPACTS) and No. 101060816 (Agroecology-TRANSECT). The first and second authors received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 727482 (DiverIMPACTS), and the second author additionally from the European Union's Horizon Europe research and innovation program under Grant Agreement No. 101060816 (Agroecology-TRANSECT).

Data Availability The datasets generated and/or analyzed during the current study are available in the Zenodo repository [https://doi.org/10.5281/zenodo.8105569].

Declarations

Ethics approval Not applicable.

Consent to participate Informed oral consent was obtained from all individual participants interviewed for the study. The data were anonymized after the end of the interviews.

Consent for publication The authors affirm that human research participants provided informed consent for publication of this study based on their anonymized information.

Conflict of interest The authors declare no competing interests.

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