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REVIEW

Facing up to drought events: Understanding the potentials and challenges within farming systems

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Abstract

Drought events, in combination with social, economic, and environmental issues such as food prices, limited access to water, and soil degradation, have made farmers more vulnerable in society. Therefore, focusing on traditional, conventional, and organic agricultural systems, this study evaluates social, economic, and environmental aspects of drought events along with the impacts of adaptation strategies on them simultaneously and globally. According to the findings, hydrological droughts have an average economic impact of approximately 1.2% on traditional agricultural systems. Furthermore, drought has significant socioeconomic effects, causing a 1.9% decrease in average livelihood in organic agricultural systems. However, drought does not have a statistically significant impact on conventional agriculture. The findings also revealed that conventional agriculture depends on expensive off-farm inputs that use large quantities of non-renewable fossil fuels. In addition, the selection of adaptation strategies in traditional agricultural systems led to an improvement in the economy (0.14%), livelihood (0.86%), and environment (0.62%). Overall, this study highlights the importance of examining different agricultural systems and their geographical distributions into account, through a global lens when assessing the impact of adaptation strategies to drought.

Keywords Hydrological drought · Water management · Socioeconomic drought · Farmers' livelihood · Geographical distributions

Introduction

Agriculture is an essential component of modern food security and has successfully met the growing demand for food during the latter half of the previous century. However, given that the system of global food production is undermining the very foundations on which it was built, it seems that meeting the global demand for food will no longer be possible in the future (Rivera-Ferre et al. 2013).

Traditional agriculture has been defined as the science or practice of farming, which includes soil cultivation for crop growth and animal husbandry for food, wool, and

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other products. The knowledge gained through thousands of years of local farming practices has led to what is contemporarily known as traditional agriculture (Singh and Singh 2017). Some of the important features of traditional agriculture systems are high efficiency, conserving wildlife, low energy sources, and being locally adaptable (Srivastava et al. 2016). Thus, traditional agro-ecosystems are seen as illustrative models of modern sustainable agricultural systems (González-Chang et al. 2016; Prasad et al. 2020). In traditional agriculture systems, there are practices, including agro-forestry (Córdova et al. 2019), field rotation (Suto et al. 2017), intercropping (Raji 2008) agricultural composting (Ronga et al. 2020), and combined crop-animal protection cultivation (Mittenzwei et al. 2017), that have the ability to improve crop productivity and tackle climate change (Ezquer et al. 2020) (Table 1).

In the last half-century, conventional agriculture has greatly increased agricultural output through high-yielding plant types, automation, and natural chemical additives (Kopczyńska et al. 2020). In the discursive formulation of the case for alternative ways to agriculture, the term "conventional agriculture" is employed (i.e. alternative to conventional agriculture). The main activities include being inherently unsustainable and large-scale, damaging the environment, generating greenhouse gases, being heavily mechanized and controlled by corporate interests, being detrimental to rural populations, and etc. (Sumberg and Giller 2022). Conventional agriculture is a production system developed in advanced industrial countries and strengthened by researchers and extension employees in colleges and universities, together with government staff in ministries and agriculture departments (Mensah and Gordon 2020). It is dependent on high-priced off-farm inputs (Kamau et al. 2018) (e.g., pesticides and fertilizer) that cause environmental waste (Goldstein et al. 2016), incorporate significant amounts of non-renewable fossil fuels (Firouzi et al. 2017), ultimately concentrating on production at the expense of small-scale farmers (Qiao et al. 2018), and undermining rural communities (Su et al. 2018). As a result, conventional agricultural practices that expand output, notably the uncontrolled application of water resources and fertilizers, are the primary drivers of emissions exposure (Amprako et al. 2020) (Table 1). Globally, organic agriculture, defined as an environmentally friendly method (Chatzisymeon et al. 2017) of production without synthetic inputs, i.e., pesticides, herbicides, and fertilizers (Röös et al. 2018), forms a small proportion of agribusiness (David and Ardiansyah 2017) within a small wider global socioeconomic system (Riar et al. 2017), and its main characteristic is cultural values (Lehtimäki and Virtanen 2020). Therefore, organic agriculture is frequently presented as a way of producing food with a low environmental effect, and it is the only agricultural system whose management procedures are legally codified in most countries (Seufert et al. 2017). In view of this, these impacts encourage a framework for local production and distribution and make healthy food available, accessible, and affordable to all (Abbott and Manning 2015). Overall, adapting the organic agriculture technique can, therefore, provide approaches to enhancing agriculture production, food safety and environmental performance (Chatzisymeon et al. 2017) (Table 1).

In terms of the differences between these agricultural systems, traditional agricultural systems are frequently defined by age-old techniques passed down through generations, focusing on manual labor, and minimum use of external inputs. In contrast, conventional agriculture adopts modern agricultural practices and technologies, depending largely on synthetic fertilizers, pesticides, and mechanization to enhance yields and efficiency. Organic agriculture, on the other hand, avoids synthetic inputs in favor of natural and environmentally friendly approaches, with a focus on biodiversity, soil health, and ecological balance.

Access to adequate quality and quantity of freshwater is one of the most pressing issues confronting humanity in the twenty-first century (Cansino-Loeza et al. 2022). Freshwater accounts for only 2.5% of the Earth's water (Bhushan

Table 1 An overview of water management strategies of agricultural systems when facing drought

Agricultural systems	Water-related features	Water management strategies
Traditional agriculture	■ Water retention system ■ Reduction in downstream peak flow ■ Providing water storages	■ No-tillage farming ■ Seasonal calendars and water allocation ■ Traditional water harvesting system (e.g., Ab-bandan)
Conventional agriculture	■ Soil moisture deficit ■ Soil compaction leading to long run water loss ■ High water intensity crops	■ Irrigating fields using surface water ■ Tillage and cropping practices leading to a decrease in soil water capacity ■ Cultivating crops such as rice, sugarcane, and cotton in regions with limited water resources
Organic agriculture	■ Steady soil moisture ■ Reduction in evaporation ■ Good water infiltration into the soil	■ Keeping soil moisture by soil organic matter ■ Reducing evaporation by a thin layer of mulch ■ Water collection by a strong soil structure containing several cavities and pores

Source: Study's findings

2020) and is significantly influenced by human activities and climate change (Ouyang et al. 2019). Many studies have confirmed significant increases in water scarcity (e.g., Trnka et al. 2019; Nouri et al. 2020), which will be exacerbated significantly in the coming decades, posing a threat to food security, environmental management, and economic growth challenges.

One of the primary uncertainties that farmers encounter is drought, typically described as water shortage compared to normal circumstances. Drought can be hydrological (shortage of water resources that are available to farmers), or it can be meteorological (caused by low rainfall). Drought is different from other climate hazards that farmers must deal with (e.g., floods), because its impacts can be felt for extended periods of time and can influence farming practices beyond the initial water scarcity (Kiem et al. 2016).

Overall, droughts occur in a wide range of climates, such as regions with high and low precipitation, being mostly associated with a decrease in the amount of rainfall over a prolonged period (e.g., a season or a year) (Tadeyo et al. 2020). Several factors that play an important role in drought are (Wang et al. 2023) temperatures (Boguszewska-Mańkowska et al. 2020), wind speed (Keeley and Syphard 2019), low relative humidity (Georgii et al. 2017), rainfall characteristics such as rainy days distributed over crop cycles, rain intensity, and duration of rain events (Berthou et al. 2019; Mardero et al. 2020). Compared with any other natural disasters, on average, drought affects more people and is more devastating (De Silva and Kawasaki 2018). In addition, there is an interaction among decreased precipitation (hydrological drought) (Kubiak-Wójcicka and Bąk 2018), stress on soil moisture (farm-drought) (Rey et al. 2017; Khan et al. 2019), reduced channel streams (hydrological drought) (Myronidis et al. 2018), and limited access to water (socioeconomic drought) (Naumann et al. 2019) triggered by economic or political causes (Madani et al. 2016; Smirnov et al. 2018).

Overall, significant challenges are posed by drought in different agricultural systems (e.g., traditional, conventional, and organic) and these challenges need to be addressed through the application of adaptation strategies.

Reviewing different agricultural systems, there are several adaptation strategies applicable to each system. For example, in terms of traditional agriculture systems, promoting rainwater harvesting can save rainwater for residential and agricultural use. A traditional approach to water management is taking place in Iran, Mazandaran, one of its local provinces (Mirzaei et al. 2017). There is a "traditional water harvesting system" named Ab-bandan (Mirzaei et al. 2019), which is man-made "water reservoirs" or "artificial wetlands" of varying sizes from 3 to 1000 ha (Giosa et al. 2018). Focusing on global aspects, the results of a study by Aliabadi et al. (2022) showed that farmers practicing traditional agriculture use different approaches to cope with drought, such as no-tillage farming, seasonal calendar, field rotation, intercropping, changing planting time, seeding before the drought, etc.

In conventional agriculture, farmers practice integrated water resources management, which is a key to water (and food) security, particularly in areas with competing interests in water resources. By implementing an efficient irrigation method, water usage is minimized, and efficiency is maximized (Rahaman and Varis 2005). Other approaches are planting high-yielding plant types and crop insurance, which contribute to income security, and provide financial support in case of drought-related crop failure (Ben-Amar et al. 2020).

By emphasizing organic agriculture, which is a sustainable livelihood strategy with decades of experience in multiple climate zones and a wide range of unique local conditions, the adaptation strategies can be built on well-established practices. The main adaptation strategies in this type of farming include drought conservation tillage, removing synthetic inputs, soil moisture monitoring and using mulch (Chatzisymeon et al. 2017; Wittwer et al. 2023).

Overall, numerous studies have evaluated the effects of farmers' adaptation strategies and the consequences of drought on agricultural systems. Most of these studies focused on how agricultural systems operated, the major costs and benefits of adaptive measures, and some other studies accounting for wider social and environmental aspects. Some studies have also excluded the farmers' adaptations strategies and only focused on the effects of drought on rural households along with ex-ante characteristics. For example, Keshavarz et al. (2017) and Udmale et al. (2014) assessed farmers' vulnerability to drought by considering the role of household characteristics.

Other studies have evaluated some adaptation strategies implemented by farmers such as using drought-tolerant crop varieties (Birthal et al. 2015), water harvesting (Bhushan 2020), non-farm activities (e.g., dairy, transporting, wood gathering) (Cunguara et al. 2011), etc. These studies frequently identified a particular agricultural system or adaptation strategy that had been demonstrated to increase the resilience of farms to drought. Overall, these studies explored the elements that enabled farmers to apply such a system or adaptation strategy.

Other groups of studies compared various drought adaptation strategies practiced by farmers in a particular location. For instance, Eriksen et al. (2005) and Le Dang et al. (2014) asked farmers to rate the effectiveness of the various drought-resilient strategies they adopted, and Venot et al. (2010) estimated the net profit from each action taken by farmers.

Another approach has been to investigate different water management strategies. In this respect, Gain et al. (2021)

suggested that it is essential to support both human well-being and the sustainable management of resources by comprehending the dynamic relationships between people and water. The difficulties facing water management today are naturally unpredictable and challenging to manage, and thus a clear recognition of the interactions and feedback between social-ecological systems and natural systems is allowed in this method. However, Basharat and Tariq (2015) suggested that groundwater can be exploited and conserved by adopting appropriate plans at both regional and local levels. In addition, overconsumption has led to increasing salinity on the surface, incursion of seawater, and groundwater mining. Li et al. (2022) demonstrated a grasp of complicated system issues of multiple cooperation of water resources, society, economics, environment, and ecology, as well as dynamics in cropping pattern modification decision-making. Furthermore, based on system dynamics, this study suggested a multidimensional joint optimization modeling technique for cropping patterns.

Reviewing the studies above, we can understand that drought events are now the least predictable of all atmospheric hazards and among the most intense meteorological events. Overall, most studies investigate adaptation strategies and water management in different ways, but to our knowledge, there is no review study analyzing drought events while simultaneously considering different agricultural systems based on social, economic, and environmental aspects. This is the research gap that the current study tries to fill by taking innovative steps to 1) review appropriate literature from Google Scholar, ISI Web of Science, Science Direct, and Scopus, to 2) assess how drought events affect major agricultural systems, such as traditional, conventional, and organic agriculture and to 3) discuss different adaptation strategies in the context of holistic social, economic, and environmental aspects.

Therefore, according to the main objectives, the following research questions will be answered:

1) What are the key factors influencing drought events' impact on social, economic, and environmental dimensions across traditional, conventional, and organic agricultural systems?
2) What are the most effective adaptation strategies employed in traditional, conventional, and organic agricultural systems in response to drought events across different geographical regions?

Methodology

By applying a meta-analysis on a global scale, this study examined the difficulties that farmers face during drought events along with their adaptation strategies as well as the effects of drought on different agricultural systems. Meta-analysis is the statistical synthesis of the findings of several original articles addressing a similar research question. The results of a meta-analysis can improve the precision of the estimates of effects, address questions not posed by the articles, resolve disputes arising from seemingly contradictory articles, and make novel hypotheses (Paul and Barari 2022). Table 2 lists dependent and explanatory variables. Quantitative effects were synthesized to verify the results obtained from the original articles (Röver and Friede 2023). The study has four phases: 1) topic selection and collection of the articles, 2) studies selection and inclusion and exclusion criteria, 3) specification of meta-analysis model, and 4) quality control and running the mate-regression.

Topic selection and compiling of articles

A systematic search was initially conducted to find relevant articles from Google Scholar, ISI Web of Science, Science Direct, and Scopus search engines from 1950 to 2023, which was followed by a thematic analysis process on keywords. The first stage was to recognize keywords based on the topic being studied, i.e., "drought events", "water scarcity", "agricultural systems", "hydrological drought", "socioeconomic drought." The next stage was to consider other keywords to get more certain articles up to the maximum searchable extent such as "adaptation strategies" and "water management." A combination of keywords related to drought types in agricultural systems were offered consecutively as follows:

Table 2 Dependent and explanatory variables

Explanatory
Hydrological drought
Socioeconomic drought
Adaptation strategy in traditional agricultural systems
Adaptation strategy in conventional agricultural systems
Adaptation strategy in organic agricultural systems
Data collection year
Continents (Africa, America, Asia, and Europe)
ISI publication
Method
Dependent
Economic aspects in traditional agricultural systems
Social aspects in traditional agricultural systems
Environmental aspects in traditional agricultural systems
Economic aspects in conventional agricultural systems
Social aspects in conventional agricultural systems
Environmental aspects in conventional agricultural systems
Economic aspects in organic agricultural systems
Social aspects in organic agricultural systems
Environmental aspects in organic agricultural systems

Source: Study's findings

1) Drought events AND water scarcity AND traditional agriculture AND hydrological drought AND socioeconomic drought
2) Drought events AND water scarcity AND conventional agriculture AND hydrological drought AND socioeconomic drought
3) Drought events AND water scarcity AND organic agriculture AND hydrological drought AND socioeconomic drought
4) Drought events AND water scarcity AND traditional agriculture AND adaptation strategies AND water management
5) Drought events AND water scarcity AND conventional agriculture AND adaptation strategies AND water management
6) Drought events AND water scarcity AND organic agriculture AND adaptation strategies AND water management

After the initial search, the retrieved records were carefully screened using predefined inclusion and exclusion criteria explained in the following sub-section.

Studies selection, inclusion and exclusion criteria

The process for including/excluding articles is shown schematically in Fig. 1. As shown in the figure, the first step was the initial search considering the above-mentioned keywords, which resulted in 2,132 articles. The second step was to include several inclusion criteria: 1) the impacts of drought events on agricultural systems must be estimated based on regression models, 2) quantitative results assessing the effect of the drought events on agricultural systems, and 3) English articles in peer-reviewed journals till October 2023. In this step, the number of original articles reached 500. The third step was the progressive search considering several exclusion criteria: 1) obvious errors, e.g., statistical inaccuracies or plagiarism, 2) use of qualitative methods without inferential statistics/analysis, and 3) the dissertation from which the article was extracted to avoid duplicate data. In this step, the number of articles narrowed down to 116 articles. The fourth step was presenting the effects of drought without measurement unit, which should be expressed as a percentage change in the dependent variable. This led to the selection of 44 primary articles for meta-analysis.

Specification of meta-analysis model

The sets of factors related to the original articles based on the economic, livelihood, and environmental effects of drought on agricultural systems were included in the meta-analysis as meta-regressions including 1) the effect of drought events on agricultural systems (in percentage), 2) the effect of adaptation strategy on economy, livelihood, and environment (in percentage), 3) temporal pattern (publication year of collected data), 4) spatial pattern (the study area), 5) publication type (ISI publication or working paper), and 6) methodology type (captured heterogeneity).

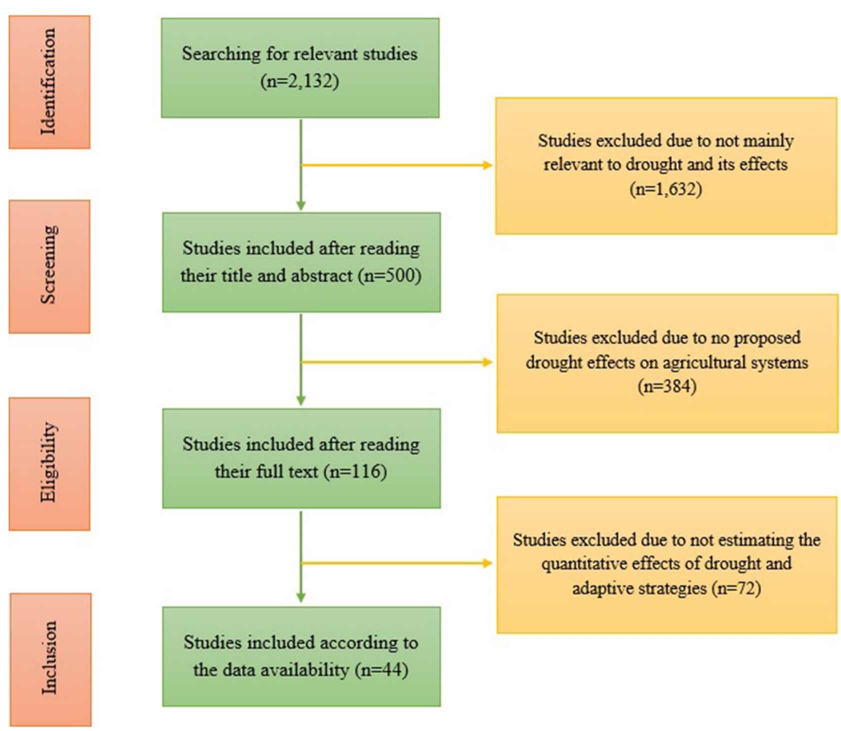

Fig. 1 The process of including or excluding articles. Source: Study's findings

In this context, enhancing the statistical significance and validity of the meta-analysis is possible, plus extracting additional information such as publication type and methodology type that may not have been included in the original articles. The general equation of a meta-analysis model is as follows:

$$M_{ij} = \alpha_0 + \sum \beta_k \; E_{ij,k} + \varepsilon_{ij} \quad (1)$$

where M_{ij} refers to the dependent variable I obtained from a given article j, $E_{ij,k}$ is the meta-regressor k and β_k is the parameter associated with meta-regressor k, which measures its impact on the estimate of the dependent variable, α_0 is the constant, μ_i is the effect size, and ε_{ij} is an error term.

Quality control and running of meta-regression

This study investigated the average effect sizes (i.e., the effect of drought and adaptation strategies in traditional, conventional, and organic agricultural systems) extracted from the primary articles to indicate the effect of drought on the economy, livelihoods, and environment of different agricultural systems.

Meta-regression can be implemented using the fixed- or random-effect model. The distinction between these two models can be due to different reasons, as follows: 1- the actual effect size in the original articles is assumed to be the same in the fixed-effect model, 2- the correlation among different observations from one or more original articles is explained through the random-effect model using cluster robust variance estimators, and 3- the random-effect model obtains consistent and efficient results compared to a fixed-effect model (Kanters 2022). Thus, the current study applied the random-effect model to implement the meta-regressions.

This study ensured the quality of the collected articles by avoiding the risk of bias (Minozzi et al. 2020). Meta-analysis studies are susceptible to publication bias because articles with results that contradict the expected direction or lack inferential statistics may overstate the effect. To avoid this problem in this study, Egger's test with funnel plot asymmetry was used to determine potential publication bias in a meta-analysis. This test is a linear regression of the intervention effect, which estimates their standard errors weighted by their inverse variance.

In the current study, three econometric models of meta-analysis were tested. First, it started from a simple model considering only the effect of drought and adaptation strategies in traditional, conventional, and organic agricultural systems. Then the spatiotemporal characteristics were included in the second model. In the third model, publication and methodology types were also added. Finally, the model with more significant statistical characteristics was selected.

The Stata version 17 (Stata Corp, College Station, TX, USA) was used to run the meta-regression.

Results

Statistical analysis

Table 3 shows the frequency percentage of primary articles based on considered variables, e.g., drought, adaptation strategy in traditional agriculture, conventional agriculture, and organic agriculture. This provides a statistical overview of observations, specifically the results presented in the primary articles. The hydrological drought showed a frequency of 68% in the primary articles. This drought is caused by decreased precipitation in different regions such as Zimbabwe (Makate and Makate 2019), China (Guo et al. 2019), and Iran (Etemadi and Karami 2016). According to the results, socioeconomic drought had a frequency of 31.8% in the primary articles, which was caused by limited access to water, insecure rural livelihood, and forced outmigration. In addition, adaptation strategies in traditional agricultural systems had a frequency of 22.7% in the primary articles. The main practices used in these articles for traditional agriculture included agroforestry, field rotation, intercropping, agricultural composting, and combined crop-animal protection cultivation. Adaptation strategies in conventional agricultural systems had a frequency of 45.4% in the primary articles. The main practices applied included high-yielding plant types, automation, and natural chemical additives. Finally, adaptation strategies in organic agricultural systems had a frequency of about 31.9% in the primary articles. The main practices applied included an environmentally friendly method of production based on removing synthetic inputs, i.e., pesticides, herbicides, and fertilizers.

Geographically, our study reflects a global interest in drought research, with significant contributions from Africa, America, Asia, and specifically Europe. Africa, America, Asia, and Europe account for 18.2%, 20.4%, 27.3%, and 34.1% of the studies, respectively. The geographical distribution of drought and adaptation strategies on economic, livelihood, and environmental impacts in agricultural systems are significant. According to publication type, 84.1% of primary articles were published in ISI journals and others were selected to be presented at the conferences and annual meetings of the scientific associations.

Output of meta-regression in traditional, conventional, and organic agricultural systems

The results of the meta-regression are indicated in Table 4. As shown in this table, the adjusted R^2 ranged from 0.11 to 0.93, representing the ratio of economic, livelihood, and environmental fluctuations for various agricultural

Table 3 The frequency percentage of primary articles based on variables included in meta-regressions as explanatory variables

Factor	Variable	Variable type	Description	Frequency (%)
Drought	Hydrological	Dummy	When the drought is the result of decreased precipitation	68.2
	Socioeconomic	Dummy	When the drought is the result of limited access to water	31.8
Adaptation strategy	Traditional	Dummy	Practices, including agroforestry, field rotation, intercropping, agricultural composting, and combined crop-animal protection cultivation	22.7
	Conventional	Dummy	Practices, including high-yielding plant types, automation, and natural chemical additives	45.4
	Organic	Dummy	Environmentally friendly practices based on removing synthetic inputs, i.e., pesticides, herbicides, and fertilizers	31.9
Temporal pattern	Data collection year	Continuous	Data collection from 1990 to 2023	100
Spatial pattern	Africa	Dummy	Study area	18.2
	America	Dummy	Study area	20.4
	Asia	Dummy	Study area	27.3
	Europe	Dummy	Study area	34.1
Publication type	ISI publication	Dummy	Publication in ISI journals	84.1
Methodology type	Method	Dummy	Method to deals with capturing heterogeneity	4.5

Source: Study's findings

systems based on the explanatory variables used in the meta-regression.

The temporal patterns (i.e., publication year of collected data) show positive impacts on traditional and organic agricultural systems. This means that increasing the data collection time by one year increases the economic and environmental impacts on traditional and organic agricultural systems. Specifically, the temporal pattern indicates a 52% increase in economic impact in traditional agricultural systems. Furthermore, the temporal pattern has a 21% greater environmental impact on organic agricultural systems. Regarding the spatial patterns, the effects of droughts on economic impacts in traditional agricultural systems are significant in America, Asia, and Europe by 2.11, -2.89, and -1.33, respectively. This means that occurring droughts in the traditional agricultural systems have negative economic impacts in Asia and Europe. Furthermore, the effect of droughts on the economic aspects of organic agricultural systems in Oceania is significantly lower than in other regions, which is approximately 3.83%. In terms of spatial patterns, livelihoods in traditional agricultural systems have been significantly influenced by droughts in American countries by -1.02. Thus, occurring droughts in the traditional agricultural systems reduce livelihoods for farmers in American countries. In addition, environment in traditional agricultural systems has been significantly influenced by droughts in Asian countries by -0.99. As a result, occurring droughts in the traditional agricultural system leads to environmental degradation in Asia. Furthermore, if the primary article is published in an ISI Journal compared to the conferences and annual meetings of the scientific associations, the economic impacts on traditional, conventional, and organic agricultural systems will show an increase by 6%, 7%, and 7%, respectively.

Drought impacts vs. adaptation strategy impacts in agriculture

Drought events in traditional agriculture cause loss of agricultural products, malnutrition of humans and livestock, loss of land, economic stagnation, increase in disease, and migration of communities, all of which threaten livelihoods at the regional and national levels. According to a study by Srivastava et al. (2016), the productivity of traditional agriculture in India's dry regions has decreased by 40% due to severe drought. Thus, farmers abandoned these agricultural areas, which were the main source of their income. In a study by Mensah and Gordon (2020) it was revealed that the occurrence of severe drought in southern Africa has led to reduced livestock grazing and less water for cattle and irrigation, which significantly affected agricultural livelihoods, resulting in food shortages in traditional agriculture. The main consequence was that livestock farmers have their livestock due to insufficient water availability. Therefore, this has greatly affected the profit margins of producers and their livelihoods and affected their loan repayments. In another similar study by Kiem et al. (2016), drought reduced the ability of conventional livestock farmers to grow forage and negatively affected the availability and cost of purchased feed in Australia. In addition, drought reduced water supplies for livestock and other farm uses. In several studies (Seufert et al. 2017; David and Ardiansyah 2017; Wittwer et al. 2023) drought decreases soil water content and soil

Table 4 Results of meta-regression

Factor	Variable	Agricultural systems								
		Traditional agriculture			Conventional agriculture			Organic agriculture		
		Economic	Social (livelihood)	Environmental	Economic	Social (livelihood)	Environ-mental	Economic	Social (livelihood)	Environmental
Drought	Hydrological	1.21**	0.16	-0.42	0.93	0.15	-6.63	-0.55	1.45	0.64
	Socioeconomic	-0.11	0.12	-0.27	0.41	-2.74	-24.69	-2.65	-1.92***	
Adaptation strategy	Traditional	0.14*	0.86***	0.62***						
	Conventional				-0.26	1.10	0.29**			
	Organic							2.04	0.04	0.03*
Temporal factor	Data collection year	0.52***	-0.03	-0.08	-0.08	-0.01	1.36	0.09	0.27	0.21*
Spatial factor	Africa	-0.30	0.03	0.18		0.01	-14.29			-2.21
	America	2.11***	-1.02**	0.18		2.73	-14.21	0.40		-0.46
	Asia	-2.89***	-0.58	-0.99**						
	Europe	-1.33**	-0.41	-0.81						
	Oceania	-0.69						-3.83*		
Publication type	ISI publication	-0.15								
Methodology type	Method	0.02	-1.16	-0.08						
Number of observations		54	44	43	6	12	18	15	2	15
Adjusted R^2		0.54	0.73	0.63	0.93	0.25	0.53	0.20	0.11	0.33

*, **, and *** indicate significant results (0.10, 0.05, and 0.01, respectively)

Source: Study's findings

organic carbon content and affects crop development and food security in organic agriculture.

As claimed by Paul and Barari (2022), applying adaptation strategies in traditional agriculture has enabled farmers to quickly react to changing climate conditions such as weather patterns and pest pressure. Rapid adaptation to climate change conditions helps farmers remain competitive and maintain the productivity of their operations. The economic benefits of climate adaptation include continued or increased agricultural production, more household incomes, improved environmental services, long-term assets, and reduced vulnerability to extreme weather events. As stated by Wittwer et al. (2023), adaptation to climate change has ecological benefits by allowing species to survive and thrive in different environmental conditions, thereby maintaining the diversity of an ecosystem. As species adapt to their environment, they develop unique characteristics that enable them to exploit different resources or habitats. Taking steps to adapt to climate change can increase resilience, meaning a greater ability to cope with change, contributing to farmers' livelihood improvement.

Discussion

Drought and adaptation strategies in agricultural systems

The drought events play significant roles on the mean economic impact in traditional agricultural systems and livelihood aspects of organic agricultural systems. Hydrological drought has significant economic consequences for the traditional agricultural system. Reduced precipitation causes hydrological drought, which raises average economic impacts in traditional agricultural systems by 1.2%. Furthermore, socioeconomic drought is associated with limited access to water and it has significant livelihood impacts on organic agricultural system, hence, resulting in 1.9% decrease in average livelihood impact in the organic agricultural system.

Previous studies' findings (e.g., Musolino et al. 2018; Edwards et al. 2019; Karmaoui et al. 2022; Nguyen et al. 2023) are consistent with our findings of the destructive effect of drought on livelihoods in the organic agricultural systems but contradict the findings of these effects on traditional systems' economies. The results of the current study point to the increase in food prices because of drought events, while other researchers emphasized the destructive effects of drought, such as reduced productivity. For example, Nguyen et al. (2023) evaluated the effects of the drought on the yields of maize and soybeans at the county level in the Southeast United States from 1979 to 2019. Their findings demonstrate that over 50% of the counties in the study region experienced significantly negative effects from drought events that occurred during the crucial development and growth stage, though the severity of these effects varied across the region due to different irrigation infrastructure and historical climatic conditions. Their results also showed a region-wide average yield drop of between 42.7% and

31.9% for maize and between 25.4% and 23.4% for soybeans due to an extremely dry event that occurred during the crucial development growth stage.

Considering the long-term impacts of drought, Karmaoui et al. (2022) investigated the social and environmental aspects with regards to desertification in arid and semi-arid regions. According to their findings, a significant influence of drought on desertification was acknowledged by the participants. The respondents indicated a high (32%) to medium (31%) impact on the economic implications for the decline in income, with a high impact direction of drought. However, the impact of the decline in agricultural yield ranged from very high (42%) to high (31%).

Edwards et al. (2019) conducted a similar study in which they evaluated surveys to investigate how the drought in Australia affected various economic and social outcomes. Their results showed that drought had a significant negative economic impact on farmers and other people working in the agricultural sector. Furthermore, those who did not work in agriculture suffered as a result of the drought along with many marginalized labor market groups suffering from poor working conditions in local economies. In contrast, Musolino et al. (2018) investigated the distributional effects of drought on agriculture and the extent of socioeconomic effects of drought in certain agricultural regions in Europe. Their results showed that, basically, based on the analysis of production and price trends, drought events were not completely harmful. Some groups, such as some producers, even benefited from the occurrence of drought.

Traditional agriculture

As the findings show, the adaptation strategy plays significant roles in the mean economic, livelihood, and environmental aspects of traditional agricultural systems. In this regard, adaptation strategies resulted in 0.14%, 0.86%, and 0.62% increases in average economic, livelihood, and environmental impacts in traditional agricultural systems, respectively. Therefore, adaptation strategy leads to global comprehensive improvement in traditional agricultural systems.

Previous studies (Altieri et al. 2015; Zeweld et al. 2021; Zobeidi et al. 2022) investigated adaptation strategies in traditional agriculture and their effects. In this regard, Zeweld et al. (2021) investigated the effects of some adaptation agricultural strategies on agricultural performance and farmers' livelihoods considering sustainable agricultural land in northern Ethiopia. Their results showed that behavioral, social, and environmental factors significantly affect the application of adaptation strategies to drought events. Altieri et al. (2015) investigated the adaptation potential of the traditional agricultural system against climate change. They showed that adaptation to climate disasters (i.e., hurricanes and droughts) is closely related to high levels of on-farm biodiversity, which is a common feature of traditional agricultural systems. Therefore, the rescue of traditional management systems along with the use of management strategies based on agroecology can be the only strong way to increase the productivity, sustainability, and adaptability of traditional agriculture under the predicted climate scenarios. They investigated how three traditional agricultural methods (i.e., biodiversity, soil management, and water harvesting) may be included into the design and management of agroecosystems, allowing farmers to employ strategies that both promote adaptation and provide financial benefits.

Conventional agriculture

According to the findings of the current study, the adaptation strategy has a significant impact on the mean environmental aspect of conventional agricultural systems. In this regard, adaptation strategies led to a 0.29% increase in average environmental impact in conventional agricultural systems. Therefore, adaptation strategy leads to comprehensive improvement in conventional agricultural systems globally.

Clearly, resource-poor households (i.e., smallholder farmers) are also seen as the most vulnerable groups to drought effects due to their inadequate facilities and supplies that act as a barrier against this vulnerability and their restricted adaptation capacity (Sofi et al. 2018). Under these conditions, if rural farmers hit a point where their livelihoods are no longer stable, they will be forced to abandon agriculture (Keshavarz and Karami 2016). It is also important to examine the susceptibility of farm families to drought.

Based on evidence, it has been proven that drought occurs cyclically, thus creating an uncertainty factor for both agricultural production and the economic situation. The recurring droughts and their consequences for many areas have been studied extensively in literature. Macholdt and Honermeier (2017) investigated the importance of farmers' diversity selection in cereal production in conventional agricultural systems and the discovery of specific crop species to adapt to drought in Germany. Their results showed that choosing climate-friendly species was very important to most respondents. The adoption of varieties with high yield levels and compatibility with the environment should be given more attention as their use is likely to improve the overall yield of cereals and reduce the risks of crop production due to drought. Sumberg and Giller (2022) critically examined conventional agriculture linked to serious challenges such as climate change. According to their results, the negative effects of conventional systems include soil degradation, both physically and biologically, as well as a major loss in soil organic matter, which ultimately reduces the soil's ability to cope with climate disturbances such as drought.

Córdova et al. (2019) using a comprehensive socio-economic and environmental information of high forest agricultural and conventional agricultural systems identified the system with better opportunities to increase adaptation against climate change in Ecuador. Their findings revealed that both agroforests and regular farmers perceived climate change in the previous decade and expected this tendency to continue in the following decade. In addition, conventional farmers were more exposed to drought, solar radiation, pests, weeds, and disease outbreaks than agroforests. They suggested the key role of agroforestry systems for drought adaptation and mitigation, especially in developing countries. In another study, Wittwer et al. (2023) investigated the ability of conservation agriculture and tillage practices to withstand drought for wheat, barley, and maize productivity. Their results indicated yield reductions due to experimental drought events of 34% for maize, 23% for barley, and 17% for wheat. As a result, the conservation agriculture system has very little ability to prevent a severe drought. However, there was a clear trend in maize, where conservation tillage during mild and experimental droughts resulted in higher average yields than tilled systems.

Organic agriculture

According to the findings, the adaptation strategy plays a significant role in the mean environmental aspect of organic agricultural systems. As can be seen, the adaptation strategy resulted in a 0.03% increase in the average environmental impact in organic agricultural systems. The crops are usually less vulnerable to drought and other natural hazards in organic agricultural systems than the crops cultivated using conventional agricultural systems. Given the growing diversity of cultivated plants, not all organic farm production is vulnerable to the same diseases or adverse weather events. Soils in the organic agricultural systems absorb more available precipitation, thus providing practical protection from drought.

Organic farmers also experience less economic loss if a complete crop failure occurs, because they have invested less in purchasing the inputs. Von Schiller et al. (2015), Ardón et al. (2016), Lebreton et al. (2016), and Schwantes et al. (2016) have estimated the effects on dissolved organic matter and ecosystems in severe drought conditions. Based on these studies, crop diversity on organic farms along with increased water holding capacity would result in drought tolerance, as well as other economic benefits. Therefore, what diversity offers is some protection against unfavorable price changes in a single system of production. More seasonal distribution of inputs is another benefit of diversified farming. Organic crop management strategies can also be a beneficial option in a period of climate change, including soil and crop characteristics that can reduce the barrier against extremes in the ecosystem. To support such changes in rural population practices, agricultural production can be maintained or restored depending on soil and water preservation and intensification of agricultural systems (Garrett et al. 2018). Based on the results of the studies by Altieri et al. (2015) and Altieri and Nicholls (2017) on organic agricultural systems for droughts, they perform better during extreme climatic conditions than conventionally managed agricultural systems. Moreover, organic agricultural systems performed significantly better in four out of five years of severe drought in the 21-year Rodale Agricultural Systems Experiment, in which two organic and one traditional crop rotations were compared. Pimentel and Burgess (2014) claimed that various organic technologies are useful for sustaining agriculture while conserving resources. Their results indicated economic effects (i.e., proper yield) and environmental effects (including more soil organic matter and nitrogen, and conservation of soil moisture and water resources) in organic farming systems under drought conditions.

Table 5 summarizes the studies in the discussion section with some more detailed information.

Novelties and limitations of this approach

The novel aspect of this study lies in its comprehensive evaluation of the social, economic, and environmental impacts of drought events on various agricultural systems (traditional, conventional, and organic) simultaneously and on a global scale. The study offers a more holistic understanding of the effects of drought and the effectiveness of adaptation strategies across various agricultural systems by taking these numerous dimensions into account at the same time. Additionally, the study highlights the interconnectedness of these aspects and emphasizes the importance of considering geographical distribution and adaptation strategies when assessing the impact of drought on agricultural systems. The study's limitation is a lack of quantitative estimation of the direct effects of drought on various social aspects, such as public safety, health issues, stress pressures, and disruption of social connections within agricultural systems. Nonetheless, the study acknowledged the existence of social impacts stemming from drought occurrences.

Conclusion

Our findings underscored the profound influence of hydrological drought, driven by reduced precipitation in regions like Zimbabwe, China, and Iran, leading to a notable shift

Table 5 A summary of the compared studies

Study	Year	Methods	Main findings	Conclusion
Traditional agriculture				
Zeweld et al	2021	A multinomial model is used to use farmers' perceptions to adapt to climate change in Northern Ethiopia	Many farmers have adopted adaptation strategies to mitigate the disturbances, such as shifting to non-farm activities, planting multipurpose trees, using organic fertilizers, cultivating different crop and livestock varieties, and using alternative water harvesting techniques	Farmers need help choosing effective adaptation strategies to reduce the risks associated with climate change, and they should have timely access to information on agricultural and climatic conditions. This will strengthen agricultural extension services and promote local institutions that raise awareness
Zobeidi et al	2022	Model of private proactive adaptation to climate change (MPPACC) and face-to-face interviews with 250 farmers in Khuzestan province, Iran	The model's results showed 49% variation in adaptive behavior and 24% in maladaptation. Also, perceived self-efficacy, perceived susceptibility, and perceived cost directly impacted both adaptive and maladaptive behaviors	MPPACC can be used to understand farmers' behavior when faced with climate change, and more importantly, maladaptation has a critical and negative impact on determining adaptive behaviors
Nguyen et al	2023	Crop yield detrending and CROPWAT model equation in the southeastern USA	Drought events that occurred during the critical development growth stage had a significant negative impact on year-to-year yield variability	Since irrigated counties are typically 50% less sensitive to drought than non-irrigated counties, irrigation may help decrease crop yield vulnerability to drought, particularly for counties that produce maize
Conventional agriculture				
Macholdt and Honermeier	2017	A broad-based survey to collect data from conventional farmers in Germany	Most farmers acknowledged the existence of climate change and its detrimental effects on cereal production. Considering this, most respondents agreed that selecting varieties that are climate-adapted was crucial. The most important varietal requirements, according to the farmers, are steadiness, eco-stability, and grain yield performance	Given that the application of varieties with high and environmentally stable yield levels is anticipated to enhance total cereal yields and lower plant production risks associated with climate change, their selection should receive more attention
Córdova et al	2019	A comprehensive socioeconomic and environmental dataset was collected from household interviews of conventional and agroforestry farmers in Ecuador's highlands	During the past ten years, farmers have noticed a clear increase in temperature and a decrease in precipitation. They also anticipated that this trend would persist in the upcoming ten years. Additionally, conventional farmers perceived more exposure to disease outbreaks, pests, weeds, droughts (40%), and solar radiation (43%) than agroforestry farmers	Due to the socioeconomic and environmental benefits of the agroforestry farming system (compared with the conventional system) in reducing vulnerability and strengthening and improving the sustainability of smallholder livelihoods, their practices should be promoted in Ecuador's highlands and other mountainous areas
Wittwer et al	2023	Agroscope's long-term farming system and tillage experiment aims to investigate how drought affects the yield of three arable crops: winter wheat, pea-barley mixture, and maize in Switzerland	For all cropping systems, there were significant and consistent yield reductions because of drought events (34% for maize, 23% for pea-barley, and 17% for winter wheat). Also, drought reduced crop uptake of nitrogen (N) and produced a positive N budget, which may lead to increased N losses following a drought period	In order to minimize the effects of drought on crop productivity, it is necessary to combine all available practices, from soil management to crop and cultivar selection. However, it is difficult to come up with workable adaptation plans for arable systems under plausible future scenarios
Organic agriculture				
Pimentel and Burgess	2014	Flow Injection Analysis (FIA) to analyze nitrate-nitrogen in leachate samples in Pennsylvania. USA	Greater amounts of nitrogen and organic matter in the soil, less energy-based inputs, yields comparable to those of conventional systems, and preservation of soil moisture and water resources, which is especially beneficial during drought events	Due to the higher market prices for organic foods, the net economic return per hectare for these crops is often equivalent to or greater than that of conventionally produced crops. Furthermore, elevated soil organic matter has been shown to be advantageous in drought years and aid in the conservation of soil and water resources
Ardón et al	2016	Water flow measurements at two sites using tipping bucket rain gauges in North Carolina, USA	Drought (20%) and salinization (29%) reduced dissolved organic carbon in similar ways, and their combined effect (49%) was additive	In the future, it is expected that saltwater intrusion into coastal freshwaters will happen more frequently, over greater areas, and for longer periods of time. This trend will become inevitable due to reductions in freshwater discharge brought on by longer and more intense droughts, as well as sea level rise
Altieri and Nicholls	2017	Conceptual resiliency framework to identify systems that have withstood climatic events and drought in Latin America	It is critical to comprehend the agroecological and organic characteristics that support the resilience of traditional agroecosystems because they can be the basis for developing adapted agricultural systems	When agroecosystems with diversified cropping systems, rich soils with organic matter, and water-harvesting practices are integrated into a complex landscape matrix, they become more resilient. How well and quickly farmers adapt to climate change will be largely determined by the effective diffusion of agroecological technologies

towards groundwater utilization for irrigation. About one-third of primary articles illustrated socioeconomic drought, which is caused by limited access to water, insecure rural livelihood, and forced outmigration. However, socioeconomic drought is a very context-based topic; thus, it should be incorporated into policy analysis, case studies, and training workshops to provide a well-rounded understanding of the challenges and potential solutions.

Our findings demonstrated a wide range of adaptation strategies across agricultural systems. Traditional methods, such as agroforestry, field rotation, and intercropping are widespread, notably in America, Asia, and Europe, demonstrating their socioeconomically beneficial effects. Conventional agriculture employs various adaptation tactics, including high-yielding plant varieties and mechanization, whereas organic systems focus on environmentally friendly practices, avoiding synthetic inputs such as pesticides and fertilizers.

Overall, among the three agricultural systems, the results of primary articles showed that organic farming has the potential to increase net returns, reduce crop failure risks, and minimize environmental impact. However, achieving such goals requires context-specific techniques for effectively mitigating drought impacts. As a result, as our study demonstrated, there must be a global interest in and recognition of the importance of studying drought events across multiple regions. Furthermore, the findings of this study highlighted the significance of adaptation strategies employed to address the socioeconomic and environmental impacts in different agricultural systems. This implies a typology of the dynamic nature of drought and the need for flexible, region-specific approaches to mitigate its effects. While the focus of this article was on adaptation strategies at the farm level, governments can help farmers adapt to climate change and drought impacts by encouraging organic agriculture and promoting organic techniques through agricultural research and extension systems. Therefore, the combination of traditional practices with ecological science can improve the adaptive capacity of organic agriculture to tackle the impacts of drought events.

In conclusion, this study emphasized the global nature of drought research, the importance of considering geographical distributions and adaptation strategies, and the widespread use of reputable journals to disseminate knowledge in the scientific community. In particular, future research studies should employ the results of such meta-analyses to characterize the risks associated with implementing adaptation measures and develop policies to help farmers assess and manage them. Also, to date, there is a huge knowledge gap among some of the policy makers on defining adaptation strategies, whether it is agricultural or non-agricultural. Thus, future research can provide more insight into a development-based perspective on adaptation measures across scales and sectors, including agriculture, to reduce farmers' vulnerability to drought events.

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Data Availability The data will be available on the request.

References

Abbott L, Manning D (2015) Soil health and related ecosystem services in organic agriculture. Sustain Agric Res 4(3):p116. https://doi.org/10.5539/sar.v4n3p116

Aliabadi V, Ataei P, Gholamrezai S (2022) Farmers' strategies for drought adaptation based on the indigenous knowledge system: the case of Iran. https://doi.org/10.1175/WCAS-D-21-0153.1

Altieri MA, Nicholls CI (2017) The adaptation and mitigation potential of traditional agriculture in a changing climate. Clim Change 140(1):33–45. https://doi.org/10.1007/s10584-013-0909-y

Altieri MA, Nicholls CI, Henao A, Lana MA (2015) Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev 35(3):869–890. https://doi.org/10.1007/s13593-015-0285-2

Amprako L, Stenchly K, Wiehle M, Nyarko G, Buerkert A (2020) Arthropod communities in urban agricultural production systems under different irrigation sources in the Northern Region of Ghana. Insects 11(8):488. https://doi.org/10.3390/insects11080488

Ardón M, Helton AM, Bernhardt ES (2016) Drought and saltwater incursion synergistically reduce dissolved organic carbon export from coastal freshwater wetlands. Biogeochemistry 127(2):411–426. https://doi.org/10.1007/s10533-016-0189-5

Basharat M, Tariq A-R (2015) Groundwater modelling for need assessment of command scale conjunctive water use for addressing the exacerbating irrigation cost inequities in LBDC irrigation system, Punjab. Pakistan Sustain Water Resour Manag 1(1):41–55. https://doi.org/10.1007/s40899-015-0002-y

Ben-Amar A, Nsarellah NE, Bouizgaren A, Mouradi M, Mahboub S, et al. (2020) Assessment of leaf rolling role in maintaining agrophysiological performances of Moroccan durum wheat cultivars under water deficit conditions. Plant Physiol Rep 25(3):436–443. https://doi.org/10.1007/s40502-020-00529-1

Berthou S, Rowell DP, Kendon EJ, Roberts MJ, Stratton RA, et al. (2019) Improved climatological precipitation characteristics over West Africa at convection-permitting scales. Clim Dyn 53(3):1991–2011. https://doi.org/10.1007/s00382-019-04759-4

Bhushan B (2020) Design of water harvesting towers and projections for water collection from fog and condensation. Philos Trans R Soc Math Phys Eng Sci 378(2167):20190440. https://doi.org/10.1098/rsta.2019.0440

Birthal PS, Negi DS, Khan MdT, Agarwal S (2015) Is Indian agriculture becoming resilient to droughts? Evidence from rice production systems. Food Policy 56:1–12. https://doi.org/10.1016/j.foodpol.2015.07.005

Boguszewska-Mańkowska D, Gietler M, Nykiel M (2020) Comparative proteomic analysis of drought and high temperature response in roots of two potato cultivars. Plant Growth Regul 92(2):345–363. https://doi.org/10.1007/s10725-020-00643-y

Cansino-Loeza B, del Munguía-López A, C, Ponce-Ortega JM, (2022) A water-energy-food security nexus framework based on optimal resource allocation. Environ Sci Policy 133:1–16. https://doi.org/10.1016/j.envsci.2022.03.006

Chatzisymeon E, Foteinis S, Borthwick AGL (2017) Life cycle assessment of the environmental performance of conventional and organic methods of open field pepper cultivation system. Int J Life Cycle Assess 22(6):896–908. https://doi.org/10.1007/s11367-016-1204-8

Córdova R, Hogarth NJ, Kanninen M (2019) Mountain farming systems' exposure and sensitivity to climate change and variability: Agroforestry and conventional agriculture systems compared in ecuador's indigenous territory of Kayambi people. Sustainability 11(9):2623. https://doi.org/10.3390/su11092623

Cunguara B, Langyintuo A, Darnhofer I (2011) The role of nonfarm income in coping with the effects of drought in southern Mozambique. Agric Econ 42(6):701–713. https://doi.org/10.1111/j.1574-0862.2011.00542.x

David W, Ardiansyah, (2017) Organic agriculture in Indonesia: challenges and opportunities. Org Agric 7(3):329–338. https://doi.org/10.1007/s13165-016-0160-8

De Silva MMGT, Kawasaki A (2018) Socioeconomic vulnerability to disaster risk: A case study of flood and drought impact in a rural Sri Lankan community. Ecol Econ 152:131–140. https://doi.org/10.1016/j.ecolecon.2018.05.010

Edwards B, Gray M, Hunter B (2019) The social and economic impacts of drought. Aust J Soc Issues 54(1):22–31. https://doi.org/10.1002/ajs4.52

Eriksen SH, Brown K, Kelly PM (2005) The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. Geogr J 171(4):287–305. https://doi.org/10.1111/j.1475-4959.2005.00174.x

Etemadi M, Karami E (2016) Organic fig growers' adaptation and vulnerability to drought. J Arid Environ 124:142–149. https://doi.org/10.1016/j.jaridenv.2015.08.003

Ezquer I, Salameh I, Colombo L, Kalaitzis P (2020) Plant cell walls tackling climate change: Biotechnological strategies to improve crop adaptations and photosynthesis in response to global warming. Plants 9(2):212. https://doi.org/10.3390/plants9020212

Firouzi S, Nikkhah A, Rosentrater KA (2017) An integrated analysis of non-renewable energy use, GHG emissions, carbon efficiency of groundnut sole cropping and groundnut-bean intercropping agro-ecosystems. Environ Prog Sustain Energy 36(6):1832–1839. https://doi.org/10.1002/ep.12621

Gain AK, Hossain S, Benson D, Di Baldassarre G, Giupponi C, et al. (2021) Social-ecological system approaches for water resources management. Int J Sustain Dev World Ecol 28(2):109–124. https://doi.org/10.1080/13504509.2020.1780647

Garrett RD, Koh I, Lambin EF, le Polain de Waroux Y, Kastens JH, Brown JC, (2018) Intensification in agriculture-forest frontiers: Land use responses to development and conservation policies in Brazil. Glob Environ Change 53:233–243. https://doi.org/10.1016/j.gloenvcha.2018.09.011

Georgii E, Jin M, Zhao J, Kanawati B, Schmitt-Kopplin P, et al. (2017) Relationships between drought, heat and air humidity responses revealed by transcriptome-metabolome co-analysis. BMC Plant Biol 17(1):120. https://doi.org/10.1186/s12870-017-1062-y

Giosa E, Mammides C, Zotos S (2018) The importance of artificial wetlands for birds: A case study from Cyprus. PLoS ONE 13(5):e0197286. https://doi.org/10.1371/journal.pone.0197286

Goldstein B, Hauschild M, Fernández J, Birkved M (2016) Urban versus conventional agriculture, taxonomy of resource profiles: a review. Agron Sustain Dev 36(1):9. https://doi.org/10.1007/s13593-015-0348-4

González-Chang M, Wratten SD, Lefort M-C, Boyer S (2016) Food webs and biological control: A review of molecular tools used to reveal trophic interactions in agricultural systems. Food Webs 9:4–11. https://doi.org/10.1016/j.fooweb.2016.04.003

Guo M, Li J, Wang Y, Long Q, Bai P (2019) Spatiotemporal variations of meteorological droughts and the assessments of agricultural drought risk in a typical agricultural Province of China. Atmosphere 10(9):542. https://doi.org/10.3390/atmos10090542

Kamau JW, Stellmacher T, Biber-Freudenberger L, Borgemeister C (2018) Organic and conventional agriculture in Kenya: A typology of smallholder farms in Kajiado and Murang'a counties. J Rural Stud 57:171–185. https://doi.org/10.1016/j.jrurstud.2017.12.014

Kanters S (2022) Fixed- and Random-Effects Models. In: Evangelou E, Veroniki AA (eds) Meta-Research: Methods and Protocols. Springer, US, New York, NY, pp 41–65

Karmaoui A, El Jaafari S, Chaachouay H, Hajji L (2022) The socio-ecological system of the pre-Sahara zone of Morocco: a conceptual framework to analyse the impact of drought and desertification. GeoJournal 87(6):4961–4974. https://doi.org/10.1007/s10708-021-10546-8

Keeley JE, Syphard AD (2019) Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. Fire Ecol 15(1):24. https://doi.org/10.1186/s42408-019-0041-0

Keshavarz M, Karami E (2016) Farmers' pro-environmental behavior under drought: Application of protection motivation theory. J Arid Environ 127:128–136. https://doi.org/10.1016/j.jaridenv.2015.11.010

Keshavarz M, Maleksaeidi H, Karami E (2017) Livelihood vulnerability to drought: A case of rural Iran. Int J Disaster Risk Reduct 21:223–230. https://doi.org/10.1016/j.ijdrr.2016.12.012

Khan ZS, Rizwan M, Hafeez M, Ali S, Javed MR, et al. (2019) The accumulation of cadmium in wheat (Triticum aestivum) as influenced by zinc oxide nanoparticles and soil moisture conditions. Environ Sci Pollut Res 26(19):19859–19870. https://doi.org/10.1007/s11356-019-05333-5

Kiem AS, Johnson F, Westra S, van Dijk A, Evans JP, et al. (2016) Natural hazards in Australia: droughts. Clim Change 139(1):37–54. https://doi.org/10.1007/s10584-016-1798-7

Kopczyńska K, Kazimierczak R, Średnicka-Tober D, Szafirowska A, Barański M, et al. (2020) The effect of organic vs conventional cropping systems on the yield and chemical composition of three courgette cultivars. Agronomy 10(9):1341. https://doi.org/10.3390/agronomy10091341

Kubiak-Wójcicka K, Bąk B (2018) Monitoring of meteorological and hydrological droughts in the Vistula basin (Poland). Environ Monit Assess 190(11):691. https://doi.org/10.1007/s10661-018-7058-8

Le Dang H, Li E, Nuberg I, Bruwer J (2014) Farmers' assessments of private adaptive measures to climate change and influential factors: a study in the Mekong Delta. Vietnam Nat Hazards 71(1):385–401. https://doi.org/10.1007/s11069-013-0931-4

Lebreton B, Beseres Pollack J, Blomberg B, Palmer TA, Adams L, et al. (2016) Origin, composition and quality of suspended particulate organic matter in relation to freshwater inflow in a South Texas estuary. Estuar Coast Shelf Sci 170:70–82. https://doi.org/10.1016/j.ecss.2015.12.024

Lehtimäki T, Virtanen MJ (2020) Shaping values and economics: Tensions and compromises in the institutionalization of organic agriculture in Finland (1991–2015). J Rural Stud 80:149–159. https://doi.org/10.1016/j.jrurstud.2020.08.023

Li L, Zhou Y, Li M, Cao K, Tao Y, et al. (2022) Integrated modelling for cropping pattern optimization and planning considering the synergy of water resources-society-economy-ecology-environment system. Agric Water Manag 271:107808. https://doi.org/10.1016/j.agwat.2022.107808

Macholdt J, Honermeier B (2017) Importance of variety choice: Adapting to climate change in organic and conventional farming systems in Germany. Outlook Agric 46(3):178–184. https://doi.org/10.1177/0030727017722420

Madani K, AghaKouchak A, Mirchi A (2016) Iran's socio-economic drought: Challenges of a water-bankrupt nation. Iran Stud 49(6):997–1016. https://doi.org/10.1080/00210862.2016.1259286
Makate C, Makate M (2019) Interceding role of institutional extension services on the livelihood impacts of drought tolerant maize technology adoption in Zimbabwe. Technol Soc 56:126–133. https://doi.org/10.1016/j.techsoc.2018.09.011
Mardero S, Schmook B, Christman Z, Metcalfe SE, De la Barreda-Bautista B (2020) Recent disruptions in the timing and intensity of precipitation in Calakmul. Mexico Theor Appl Climatol 140(1):129–144. https://doi.org/10.1007/s00704-019-03068-4
Mensah AM, Gordon C (2020) Strategic partnerships between Universities and non-academic institutions for sustainability and innovation: Insights from the University of Ghana. In: Gasparatos A, Ahmed A, Naidoo M, Karanja A, Fukushi K, et al. (eds) Sustainability Challenges in Sub-Saharan Africa I: Continental Perspectives and Insights from Western and Central Africa. Springer, Singapore, pp 245–278
Minozzi S, Cinquini M, Gianola S, Gonzalez-Lorenzo M, Banzi R (2020) The revised Cochrane risk of bias tool for randomized trials (RoB 2) showed low interrater reliability and challenges in its application. J Clin Epidemiol 126:37–44. https://doi.org/10.1016/j.jclinepi.2020.06.015
Mirzaei A, Knierim A, Fealy Nahavand S, Mahmoudi H (2017) Gap analysis of water governance in Northern Iran: A closer look into the water reservoirs. Environ Sci Policy 77:98–106. https://doi.org/10.1016/j.envsci.2017.08.004
Mirzaei A, Knierim A, Fealy Nahavand S, Shokri SA, Mahmoudi H (2019) Assessment of policy instruments towards improving the water reservoirs' governance in Northern Iran. Agric Water Manag 211:48–58. https://doi.org/10.1016/j.agwat.2018.09.020
Mittenzwei K, Persson T, Höglind M, Kværnø S (2017) Combined effects of climate change and policy uncertainty on the agricultural sector in Norway. Agric Syst 153:118–126. https://doi.org/10.1016/j.agsy.2017.01.016
Musolino DA, Massarutto A, de Carli A (2018) Does drought always cause economic losses in agriculture? An empirical investigation on the distributive effects of drought events in some areas of Southern Europe. Sci Total Environ 633:1560–1570. https://doi.org/10.1016/j.scitotenv.2018.02.308
Myronidis D, Ioannou K, Fotakis D, Dörflinger G (2018) Streamflow and hydrological drought trend analysis and forecasting in cyprus. Water Resour Manag 32(5):1759–1776. https://doi.org/10.1007/s11269-018-1902-z
Naumann G, Vargas WM, Barbosa P, Blauhut V, Spinoni J, et al. (2019) Dynamics of socioeconomic exposure, Vulnerability and impacts of recent droughts in Argentina. Geosciences 9(1):39. https://doi.org/10.3390/geosciences9010039
Nguyen H, Thompson A, Costello C (2023) Impacts of historical droughts on maize and soybean production in the southeastern United States. Agric Water Manag 281:108237. https://doi.org/10.1016/j.agwat.2023.108237
Nouri H, Stokvis B, Chavoshi Borujeni S, Galindo A, Brugnach M, et al. (2020) Reduce blue water scarcity and increase nutritional and economic water productivity through changing the cropping pattern in a catchment. J Hydrol 588:125086. https://doi.org/10.1016/j.jhydrol.2020.125086
Ouyang X, Hao X, Zheng L, Zhuo B, Liu Y (2019) Early to mid-Holocene vegetation history, regional climate variability and human activity of the Ningshao Coastal Plain, eastern China: New evidence from pollen, freshwater algae and dinoflagellate cysts. Quat Int 528:88–99. https://doi.org/10.1016/j.quaint.2019.05.027
Paul J, Barari M (2022) Meta-analysis and traditional systematic literature reviews—What, why, when, where, and how? Psychol Mark 39(6):1099–1115. https://doi.org/10.1002/mar.21657
Pimentel D, Burgess M (2014) An Environmental, Energetic and economic comparison of organic and conventional farming systems. In: Pimentel D, Peshin R (eds) Integrated Pest Management: Pesticide Problems, vol 3. Springer. Netherlands, Dordrecht, pp 141–166
Prasad AKM, Roy S, Sen S, Neave S, Nagpal A, et al. (2020) Impact of different pest management practices on natural enemy population in tea plantations of Assam special emphasis on spider fauna. Int J Trop Insect Sci 40(3):629–635. https://doi.org/10.1007/s42690-020-00111-0
Qiao Y, Martin F, Cook S, He X, Halberg N, et al. (2018) Certified organic agriculture as an alternative livelihood strategy for small-scale farmers in China: A case study in Wanzai County, Jiangxi Province. Ecol Econ 145:301–307. https://doi.org/10.1016/j.ecolecon.2017.10.025
Rahaman MM, Varis O (2005) Integrated water resources management: evolution, prospects and future challenges. Sustain Sci Pract Policy 1(1):15–21. https://doi.org/10.1080/15487733.2005.11907961
Raji JA (2008) The feasibility of intercropping kenaf with sorghum in a small-holder farming system. J Sustain Agric 32(2):355–364. https://doi.org/10.1080/10440040802171382
Rey D, Holman IP, Knox JW (2017) Developing drought resilience in irrigated agriculture in the face of increasing water scarcity. Reg Environ Change 17(5):1527–1540. https://doi.org/10.1007/s10113-017-1116-6
Riar A, Mandloi LS, Poswal RS, Messmer MM, Bhullar GS (2017) A Diagnosis of biophysical and socio-economic factors influencing farmers' choice to adopt organic or conventional farming systems for cotton production. Front Plant Sci 8:1289. https://doi.org/10.3389/fpls.2017.01289
Rivera-Ferre MG, Ortega-Cerdà M, Baumgärtner J (2013) Rethinking study and management of agricultural systems for policy design. Sustainability 5(9):3858–3875. https://doi.org/10.3390/su5093858
Ronga D, Mantovi P, Pacchioli MT, Pulvirenti A, Bigi F, et al. (2020) Combined effects of dewatering, Composting and pelleting to valorize and delocalize livestock manure. Impr Agric Sustain Agron 10(5):661. https://doi.org/10.3390/agronomy10050661
Röös E, Mie A, Wivstad M, Salomon E, Johansson B, et al. (2018) Risks and opportunities of increasing yields in organic farming. A Review Agron Sustain Dev 38(2):14. https://doi.org/10.1007/s13593-018-0489-3
Röver C, Friede T (2023) Using the bayesmeta R package for Bayesian random-effects meta-regression. Comput Methods Programs Biomed 229:107303. https://doi.org/10.1016/j.cmpb.2022.107303
Schwantes AM, Swenson JJ, Jackson RB (2016) Quantifying drought-induced tree mortality in the open canopy woodlands of central Texas. Remote Sens Environ 181:54–64. https://doi.org/10.1016/j.rse.2016.03.027
Seufert V, Ramankutty N, Mayerhofer T (2017) What is this thing called organic? – How organic farming is codified in regulations. Food Policy 68:10–20. https://doi.org/10.1016/j.foodpol.2016.12.009
Singh R, Singh GS (2017) Traditional agriculture: a climate-smart approach for sustainable food production. Energy Ecol Environ 2(5):296–316. https://doi.org/10.1007/s40974-017-0074-7
Smirnov O, Steinwand MC, Xiao T, Zhang M (2018) Climate impacts, Political Institutions, and leader survival: Effects of droughts and flooding precipitation. Econ Disasters Clim Change 2(2):181–201. https://doi.org/10.1007/s41885-018-0024-7
Sofi PA, Baba ZA, Hamid B, Meena RS (2018) Harnessing soil rhizobacteria for improving drought resilience in legumes. In: Meena RS, Das A, Yadav GS, Lal R (eds) Legumes for Soil Health and Sustainable Management. Springer, Singapore, pp 235–275

Srivastava P, Singh R, Tripathi S, Raghubanshi AS (2016) An urgent need for sustainable thinking in agriculture – An Indian scenario. Ecol Indic 67:611–622. https://doi.org/10.1016/j.ecolind.2016.03.015

Su M, Sun Y, Min Q, Jiao W (2018) A community livelihood approach to agricultural heritage system conservation and tourism development: Xuanhua Grape Garden Urban Agricultural Heritage Site. Hebei Province of China Sustainability 10(2):361. https://doi.org/10.3390/su10020361

Sumberg J, Giller KE (2022) What is 'conventional' agriculture? Glob Food Secur 32:100617. https://doi.org/10.1016/j.gfs.2022.100617

Suto H, Kanao T, Nagasawa T, Mizushima K, Sato R (2017) Zero-dc-field rotation-direction-dependent magnetization switching induced by a circularly polarized microwave magnetic field. Sci Rep 7(1):13804. https://doi.org/10.1038/s41598-017-13770-w

Tadeyo E, Chen D, Ayugi B, Yao C (2020) Characterization of spatio-temporal trends and periodicity of precipitation over malawi during 1979–2015. Atmosphere 11(9):891. https://doi.org/10.3390/atmos11090891

Trnka M, Feng S, Semenov MA, Olesen JE, Kersebaum KC, et al. (2019) Mitigation efforts will not fully alleviate the increase in water scarcity occurrence probability in wheat-producing areas. Sci Adv 5(9):eaau2406. https://doi.org/10.1126/sciadv.aau2406

Udmale P, Ichikawa Y, Manandhar S, Ishidaira H, Kiem AS (2014) Farmers′ perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. Int J Disaster Risk Reduct 10:250–269. https://doi.org/10.1016/j.ijdrr.2014.09.011

Venot J-P, Jella K, Bharati L, George B, Biggs T, et al. (2010) Farmers' adaptation and regional land-use changes in irrigation systems under fluctuating water supply. South India J Irrig Drain Eng 136(9):595–609. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000225

von Schiller D, Graeber D, Ribot M, Timoner X, Acuña V, et al. (2015) Hydrological transitions drive dissolved organic matter quantity and composition in a temporary Mediterranean stream. Biogeochemistry 123(3):429–446. https://doi.org/10.1007/s10533-015-0077-4

Wang Y, Wang Y, Chen Y, Chen H, Li X, et al. (2023) Spatial and temporal characteristics of Drought Events in Southwest China over the past 120 years. Remote Sens 15(12):3008. https://doi.org/10.3390/rs15123008

Wittwer RA, Klaus VH, Miranda Oliveira E, Sun Q, Liu Y, et al. (2023) Limited capability of organic farming and conservation tillage to enhance agroecosystem resilience to severe drought. Agric Syst 211:103721. https://doi.org/10.1016/j.agsy.2023.103721

Zeweld W, Huylenbroeck GV, Tesfay G, Speelman S (2021) Sustainable agricultural practices as a response to climate change in Northern Ethiopia. In: Luetz JM, Ayal D (eds) Handbook of Climate Change Management: Research, Leadership, Transformation. Springer International Publishing, Cham, pp 1245–1276

Zobeidi T, Yaghoubi J, Yazdanpanah M (2022) Farmers' incremental adaptation to water scarcity: An application of the model of private proactive adaptation to climate change (MPPACC). Agric Water Manag 264:107528. https://doi.org/10.1016/j.agwat.2022.107528