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Sustainable Farmland Management: Integrating Land Use Planning and Farming System Adaptation

Doctoral Thesis

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Declaration

I hereby declare that the dissertation entitled "Sustainable Farmland Management: Integrating Land Use Planning and Farming System Adaptation" submitted for the degree of Doctor in Philosophy in the study program Applied and Landscape Ecology, is my original work guided by my supervisor. All sources of information, text, illustrations, tables, and images have been cited specifically.

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Abstract

Land is a fundamental resource for human society. Rapid economic development, population growth, urbanization, and industrialization put pressure on countries with limited natural resources. Growing demand for non-agricultural uses, combined with a scarcity of land to meet these demands, resulted in an increasing amount of agricultural land being converted to non-farming uses.

Accordingly, this thesis investigates three interrelated dimensions of farmland sustainability: the role of land consolidation in mitigating land degradation, the capacity of farming systems to adapt to drought events, and the impact of land tenure security on agricultural land conversion to urban use. The thesis investigates how integrated land management strategies can improve agricultural resilience by combining literature synthesis, meta-analysis, and comparative evaluation.

The first part of the study highlights the importance of land management measures in reducing fragmentation and promoting the long-term sustainability of farmland. Our findings demonstrate that land management measures have a consistent positive effect when specifically targeted, and there is also a significant synergy between the effects of these measures. The second part of the study investigates how different farming systems—conventional, traditional, and organic—respond to drought events using adaptation strategies. The results indicate that drought negatively impacts farmers' livelihoods in organic farming, though it does not significantly affect conventional systems. Despite this, conventional agriculture remains dependent on costly, fossil fuel-intensive inputs. In contrast, traditional farming systems benefit from adaptation strategies, which improve economic outcomes, livelihoods, and environmental sustainability. The final part of the study provides quantitative insights into the effects of land tenure variables including land tenure type, legal status, cadastral assignment, and land ownership on agricultural land conversion to urban use. As our findings show, owner-farmed, titled, and designated agricultural lands demonstrate strong protection against urban expansion, and secure tenure significantly reduces conversion pressures. Overall, the thesis provides empirical support and policy-relevant insights into current debates on farmland preservation.

Keywords: Farmland conversion; Meta-regression; Farmers' livelihood; Geographical distributions; Sustainable land management; Environmental degradation

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Chapter I – Thesis Preface

Foreword

Identifying more sustainable forms of farmland management requires an understanding that farmlands produce far more than crops and that rural lands can provide much more than agricultural products. Part of the scientific community has made a significant effort over the last decade to change our perspective on agriculture and rural development from optimizing agricultural productivity to managing farmlands that provide a variety of benefits.

Farmland interacts with natural systems in the provision of services to society. However, along with population growth and urban area expansion, the pressure on farmland intensifies, primarily responsible for environmental disasters and land degradation, including loss of soil organic matter and biodiversity, soil erosion, land conversion, floods, and water scarcity. To secure livelihoods and lessen rural poverty, scholars emphasize that adopting sustainable practices is an environmental and socioeconomic imperative.

Fortunately, over the past few decades, there has been a change in the paradigms and rhetoric that support sustainable farmland management discourse. The idea that land degradation is primarily a social and economic phenomenon rather than merely the product of informational or technological shortcomings is becoming more widely acknowledged. Therefore, social, economic, and political solutions are also required, and better land management techniques must get past the various institutional, market, and governance barriers that discourage farmer adoption. However, this broader viewpoint has been slowly incorporated into many research frameworks to plan, guide, and evaluate land management interventions. Overall, to fully understand the complexities of the many issues facing agriculture today, multidisciplinary, multidimensional analysis and traditional biophysical and socioeconomic assessments are still noticeably lacking.

The current thesis aims to explore how to address the pressing natural and socioeconomic challenges of our time, which are affecting the sustainability of farmland management. Specifically, by focusing on the effects of drought, land degradation, and agricultural land conversion to urban use, the current thesis attempts to provide practical insights for policymakers, farmers, and stakeholders. Therefore, it is an interdisciplinary study combining environmental science, socioeconomics, and land use planning to propose a comprehensive framework for sustainable farmland management.

Research Motivation

The initial spark of my interdisciplinary research was ignited during my master's studies, through which I modeled the integration of ecological indicators (e.g., water and CO_2 emissions footprints) into economic development decisions. I tried to show that this integration is essential, especially in modeling and constructing decision support systems in response to natural resource management (e.g., water, land, and ecosystem services) and mitigating climate change effects. So, after publishing the results of my master's thesis (i.e., *Integrating ecological impact indicators into economic restructuring decisions*), I started to focus on climate-resilient agricultural landscape systems and socioeconomic impact assessment of land use change by collaborating with a scholar who was an expert in this field. This research-based collaboration resulted in a series of articles relevant to interdisciplinary topics such as climate change, sustainability, and land use change (e.g., *Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture*; *Climate smart agriculture: Mitigation and adaptation strategies at the global scale*; *Do changes in land use and climate change overlap? An analysis of the World Bank Data*, etc.)

Later, I was drawn to the complex interactions between the socioeconomic aspects of land use change and sustainable farmland management when it came time to select the topic for my PhD dissertation. This topic stood out to me because it tackles some of the most critical global issues, such as ensuring food security, reducing land degradation, and fostering climate resilience to face drought, in addition to bridging my academic interests in environmental sustainability, economics, and land use planning. The socioeconomic drivers and effects of land use change are still less understood, although the environmental aspects of farmland management have been thoroughly studied in the literature. Therefore, I intend to add a novel perspective to the topic by concentrating on these little-known aspects and highlighting how socioeconomic decision-making shapes sustainable agricultural landscapes.

This study is particularly relevant because it offers a comprehensive understanding of how socioeconomic structures and land-use regulations can affect farmland sustainability in the face of growing urbanization and climate change pressures. This study seeks to provide policymakers and practitioners with practical insights to prioritize strategies that balance environmental integrity, economic viability, and societal needs in a world that is changing quickly and where competing demands pose an increasing threat to agricultural lands. My dissertation attempts to fill important gaps in the literature and help create more flexible and sustainable land management systems by proposing an integrated framework for tackling these issues.

Objectives of the thesis

The main objective of this thesis is to contribute to the body of knowledge on sustainable farmland management while addressing the environmental and socioeconomic issues caused by land use change. The study's specific objectives are to: (1) examine the causes and effects of agricultural land conversion to urban use, with an emphasis on the socioeconomic factors that influence these changes; (2) assess how drought and land degradation compound each other's effects on agricultural productivity and rural livelihoods, and determine how well current land management practices mitigate these effects; and (3) suggest policy recommendations and adaptive strategies to increase agricultural landscapes' resilience to socioeconomic and natural pressures. This thesis is based on three studies, each contributing unique insights into land use planning and sustainability.

The first study examines the effects of land consolidation projects implemented under different natural and socioeconomic conditions considering the fact that land fragmentation is a severe issue, but no significant attempts have been made to address the topic. Thus, the main goal of this study is to investigate the effects of land consolidation on land degradation and to supplement the data analysis with maps created in ArcGIS.

The second study evaluates the social, economic, and environmental aspects of drought events along with the impacts of adaptation strategies being practiced by farmers. Therefore, the main goals are to assess the key factors influencing drought events' impact on social, economic, and environmental dimensions across traditional, conventional, and organic agricultural systems and discover the most effective adaptation strategies employed in these farming systems in response to drought events across different geographical regions.

Following the insight from the second study, the third study focuses on the effects of land tenure variables on agricultural land conversion to urban use through the analysis of land tenure type (expressed as land farmed by its owner and land farmed by a tenant), legal status (titled land and untitled land), cadastral assignment (designated and not-designated agricultural land), and land ownership (private land and communal land). Here, the main goal is to better understand the links between land tenure security and agricultural land conversion.

Thesis structure

The thesis is a monograph organized into three parts and six chapters. **Part I** includes a preface, research motivation, and study objectives, followed by a theoretical background consisting of an in-depth literature review to contextualize the research. **Part II** presents the main research and consists of three chapters categorized as independent studies, collectively contributing to a comprehensive understanding of sustainable farmland management and the associated challenges. **Part III** discovers the link between individual studies and their contributions to the findings. The studies are as follows:

Study 1 - Impacts of land consolidation on land degradation: A systematic review

Study 2 - Facing up to drought events: Understanding the potentials and challenges within farming systems

Study 3 - Impacts of land tenure security on the conversion of agricultural land to urban use

Chapter II – Theoretical Background

Importance of sustainable farmland management in the global context

Sustainable farmland management is essential to tackle pressing global challenges such as food insecurity, environmental degradation, and rural poverty. With this strategy, agricultural landscapes are managed to maximize productivity while maintaining social and ecological well-being. However, first, sustainable land management needs to be discussed. Sustainable land management, according to Smyth and Dumanski et al. (1993), is a collection of technologies, regulations, and initiatives designed to combine socioeconomic concepts with environmental considerations to preserve and improve productivity, lower production risk, strengthen soil's ability to withstand degradation processes, safeguard the potential of natural resources, prevent soil and water quality degradation, be economically feasible, be socially acceptable, and guarantee that the community can benefit from better land management. The importance of sustainable farmland management is explored below from two key aspects: socioeconomic advantages for rural communities and environmental preservation practices.

Socioeconomic advantages for rural communities

Since rural communities are often the most susceptible to environmental and agricultural challenges, sustainable farmland management is also essential to raising their standard of living. These practices help minimize poverty and promote social stability by emphasizing fair resource access and building resilience. Studies showing that farmers who implemented sustainable practices experienced increased income stability clearly show economic benefits. For example, Aronica et al. (2023) investigated how open they were to long-term development ideas in Sicilian farms. Their findings showed that sustainable management practices increased farm income and encouraged rural communities to grow through improved management, diversification, direct marketing, value-added projects, and agritourism.

In another study in Central Germany by Scherzinger et al. (2024), they conducted an experiment including three grassland and two cropland types of land use, with intensive management and sustainable management. The findings indicate that for most scenarios in both cropland and grassland, ecological multifunctionality is reduced by intensive management and the future climate. Furthermore, for both grassland and cropland, the economic multifunctionality measure is almost 2 times higher for sustainable practices compared to intensive management.

Similarly, the beneficial external effects of farms on the value of European Agricultural Landscapes were evaluated through an analysis of 28 case studies from five European countries. Most farms showed a correlation between high nature-value farmland and protected areas and traditional land use forms, suggesting that sustainable practices support both socioeconomic benefits and environmental conservation (Slámová and Belčáková, 2019).

Overall, social cohesion and capacity building are promoted by sustainable farmland management. Farmers can adopt new methods and bargain for better market conditions thanks to training programs and cooperative models that promote knowledge exchange and group efforts. Beyond just helping individual households, these socioeconomic advantages also support regional growth and the fight against poverty (FAO, 2021).

Environmental preservation practices

Ecosystems are significantly impacted by agricultural practices, which affect carbon sequestration, water cycles, and biodiversity. Sustainable farmland management focuses on methods that protect and improve these ecosystem services. For instance, preserving healthy soil with organic amendments and less tillage enhances crop yields while promoting carbon sequestration and reducing climate change. Another important advantage is the preservation of biodiversity. Studies have demonstrated that in contrast to monoculture systems, agroforestry systems—which combine crops and trees—can sustain more significant levels of biodiversity. Additionally, these systems provide vital ecosystem services that are necessary for sustainable agriculture, like pollination, habitat creation, and natural pest control (Caldwell et al., 2022; EIT Food, 2020).

Another important factor is water management, especially in the face of drought. Freshwater resources have been overused and contaminated by unsustainable farming methods, but sustainable methods like drip irrigation and rainwater harvesting reduce water waste and improve supply for later use. Global studies emphasize the importance of efficient water management practices to support agricultural productivity while conserving water resources. For example, Visser et al. (2024) investigated human-water decision-making in agricultural areas by applying a political ecology framework to comprehend how and why farmers confront severe water shortages and make livelihood decisions and how these decisions are influenced by larger socio-political contexts. Their findings showed that the consequences of severe and prolonged drought have led to a governance structure for resource management that restricts farmer decision-making to the parameters of the recently developed California water policy.

In a systematic review article by Ingrao et al. (2023), they investigated physical and economic water scarcity in agriculture along with practices and tools to reduce water wastage. Improving irrigation techniques and technologies was a key strategy for decreasing water scarcity. Furthermore, many regions of the world use solar-powered "reverse-osmosis" to create irrigation water from salty water, which lessens the need to draw fresh water from underground aquifers.

Maintaining ecosystem services and protecting the environment depends heavily on sustainable farmland management. Farmers help preserve essential ecosystem functions, protect natural habitats, and sequester carbon by implementing agroforestry, soil health improvement, biodiversity enhancement, and efficient water use. In addition to reducing environmental problems like water scarcity, climate change, and land degradation, these methods strengthen agricultural systems' resilience and guarantee their sustainability for future generations.

Current challenges facing farmland sustainability

This section discusses some of the most pressing challenges to sustainable farmland management that threaten environmental stability and agricultural productivity. These challenges can be broadly categorized as natural, socioeconomic, or a combination of both, which are the hardest to combat. Drought and water scarcity are among the most serious natural threats, reducing crop yields while also jeopardizing long-term soil health and water resource availability (Kiem et al., 2016). On the other hand, land degradation, characterized by soil erosion, nutrient depletion, and salinization, is frequently caused by both unsustainable agricultural practices and climatic stressors, making it a complex issue that could derived from both natural and socioeconomic domains (Abu Hammad and Tumeizi, 2012; Ferrara et al., 2020). A key socioeconomic challenge is the conversion of agricultural land to urban use, particularly in rapidly developing regions, where farmland is increasingly lost to residential, industrial, and infrastructure growth (Rondhi et al., 2018). This process is exacerbated by urban sprawl, which frequently results in land use conflicts, especially when land tenure systems are weak or informal, leading to disputing claims and fragmented landscapes (Phuc et al., 2014).

Drought and water scarcity

Drought, which is commonly defined as a shortage of water in comparison to normal conditions, is one of the main uncertainties that farmers face. There are two types of droughts: meteorological (caused by low rainfall) and hydrological (caused by a

shortage of water resources available to farmers). Drought differs from other climate hazards that farmers face, like floods, in that its effects last for a long time and can affect farming practices after the initial water scarcity (Kiem et al., 2016). Droughts are usually associated with a reduction in rainfall over an extended period of time (e.g., a season or a year) and can occur in a wide range of climates, including areas with high and low precipitation (Tadeyo et al., 2020). Temperatures, wind speed, low relative humidity, rainfall characteristics (such as the number of rainy days spread across crop cycles), rain intensity, and duration of rain events are some of the key factors that contribute to drought (Keeley and Syphard, 2019; Mardero et al., 2020; Y. Wang et al., 2023).

Overall, the most significant impact of drought is on agricultural systems, which need to be addressed by farmers' adaptation strategies. According to a study by Lesk et al. (Lesk et al., 2016), droughts reduced crop yields worldwide by 21% for maize and 10% for cereals. Food insecurity and economic hardship are also disproportionately experienced by smallholder farmers in arid and semi-arid areas, who frequently do not have access to irrigation. However, the socioeconomic impacts of droughts extend beyond agriculture. For example, frequent droughts have caused mass migrations, livestock losses, and conflicts over reducing water resources in Sub-Saharan Africa, where more than 60% of the population relies on rain-fed agriculture (Mensah and Gordon, 2020). Similarly, severe droughts in Australia from 2000 to 2010 caused agricultural output to drop by 26%, which had an impact on the entire country's economy (Kiem et al., 2016).

Land degradation

Since the term "land degradation" is relatively new (Xie et al., 2020), different definitions and theories about the causes and consequences of this phenomenon are used by research teams. While some studies only consider human activity as the cause of this phenomenon (Ferrara et al., 2020), others also take natural processes into account (Gryczak et al., 2020). Basically, land degradation, which includes processes like soil erosion, nutrient depletion, and desertification, is a significant obstacle to sustainable farmland management. Several studies (Abu Hammad and Tumeizi, 2012; Vu et al., 2014) indicated that land degradation is a global phenomenon with natural and socioeconomic causes and effects. Additionally, they proposed that measures to increase farmer environmental awareness, environmental standards, laws, and regulations, as well as a decrease in land mismanagement, are necessary to address socioeconomic land degradation. Addressing land degradation requires context-specific implementation strategies and a thorough understanding of its causes, effects, and potential solutions.

The main areas of land-degradation research currently are development trend simulation and prediction using quantitative models, prevention and ecological reconstruction, driving factor identification using various techniques at various scales, and evaluation and monitoring based on various data sources. For instance, to build a new land-degradation monitoring model, Yue et al. (2016) used a back propagation (BP) neural network and expert knowledge. Between 1990 and 2010, they observed and assessed the land degradation in northern China's Ordos Plateau. The findings demonstrate that the Ordos Plateau's land degradation has been reversed, with most regions transforming from hotspots for land degradation to smaller areas with altered land use. In another study, from 2001 to 2016, Abdel-Kader (2019) investigated the causes of land degradation along Egypt's northwest coast using the binomial logistic regression method. The findings indicate that, in decreasing order, altitude, slope, land range, vegetation index, negative change of vegetation index, bare land, mid-slope position, and multi-resolution ridge top flatness index are the primary variables that contribute to land degradation.

Agricultural land conversion to urban use

One of the most significant challenges to sustainable farmland management is socioeconomic inequality. Among others, the conversion of agricultural land to urban use is driven by population growth, urbanization, and economic development. In addition to decreasing the amount of arable land available, this phenomenon also disrupts ecological balance, food security, and rural livelihoods. With an emphasis on urban sprawl, land competition, and case studies from China, India, and Iran, this section explores the challenges of agricultural land conversion. The conversion of land from agricultural to urban uses is the general definition of agricultural land conversion (Azadi et al., 2011). According to Tan et al. (2009) agricultural land conversion is a phenomenon that is inevitable during population growth and economic development. The intensity, trends, and drivers of agricultural land conversion vary from one country to another. The primary socioeconomic drivers of agricultural land conversion are high population density, rapid economic growth, and the urbanization process (Ho and Lin, 2004a). The conversion of agricultural land is significantly influenced by the urbanization process and rural-urban migration, which have been extensively studied.

Industrialization leads to the conversion of farmland in China's coastal cities, according to Ho and Lin (2004a) who also found that China's industrialization process is often accompanied by urbanization, which leads to the conversion of farmland. Agricultural land conversion is affected by rapid population growth because growing populations require expanding built areas to accommodate more housing and job opportunities. Fazal (2001) examined how urbanization affects agricultural land conversion in India. They claimed that the urbanization pattern and rapid population growth in developing, and underdeveloped countries put pressure on land and affect

farmers' livelihoods and the availability of ecosystem goods and services. In a more recent study, Rondhi et al. (2018) stated that agricultural land conversion is an incentive-driven process to convert agricultural land, decreasing agricultural production and threatening food security.

Urban sprawl and land conflict

Urban sprawl is another important driver of agricultural land conversion. Developed countries are better at controlling urban development and agricultural land conversion (Phuc et al., 2014), despite the fact that land conversion for urban expansion is growing quickly, particularly in megacities worldwide (Azadi et al., 2011). Nevertheless, there is a lack of a suitable strategy for managing urban development in developing countries, such as Iran. Consequently, urbanization is linked to a form of sprawl in these countries. Azadi et al. (2016) identified the driving forces behind agricultural land conversion in Iran. According to their findings among other socioeconomic drivers such as "more profitability of non-agriculture sectors," "excessive rising of land prices," "farmers' income instability," and "inheritance laws," "urban sprawl" is one of the leading drivers causing agricultural land conversion.

This uncontrolled expansion of cities into surrounding rural areas leads to the fragmentation of agricultural landscapes and increased land resource conflict. Overall, the increase in agricultural land conversion rates creates a conflict between protecting agricultural land, achieving food security, and developing industrialization for employment (Zhang et al., 2023). There are numerous issues with farming households migrating from rural to urban areas and with suburbanization surrounding cities. For example, marginalized households are concerned about conflicts with other neighbors and the resulting destruction, such as equipment damage. Thus, as the agricultural sector declines, competition for jobs in the non-agricultural sector intensifies (Güneralp et al., 2017). There is a possibility that the agricultural industry will collapse, and the local economy's survival will be threatened if funding for the sector is suddenly reduced along with its sources of income.

To summarize this section, sustainable farmland management is at the heart of addressing pressing global issues such as drought, land degradation, and the growing agricultural land conversion to urban use. Thus, to ensure food supplies, maintain ecosystem services, and improve rural livelihoods, this field combines ecological, economic, and social perspectives. Innovative, multidisciplinary approaches are urgently needed to ensure agricultural systems' resilience and productivity as resource scarcity, urbanization, and climate change put additional strain on farmland.

Overall, this study aims to provide significant insights into sustainable land-use practices, their application in various regions, and their broader implications for global

sustainability by building on previous research and identifying important knowledge gaps. The following sections in this thesis will go into greater detail about these challenges and opportunities.

Chapter III – Study 1

Title: Impacts of land consolidation on land degradation: A systematic review

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Authors' contribution:

Conception and design of the study were planned by K. Janečková; Data collection and analysis was performed by P. Sklenička; visualization was carried out by I. C. Bohnet; first draft was written by F. Lowther Harris with contribution from A. van den Brink, S. Movahhed Moghaddam, V. Fanta, V. Zástěra and H. Azadi. All authors read and approved the final manuscript.

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Research article

Impacts of land consolidation on land degradation: A systematic review

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ABSTRACT

Land consolidation (LC) is a widespread form of rural planning and is often presented as an important tool for mitigating land degradation. We therefore decided to make a systematic review of the effects of LC projects implemented under different natural and socio-economic conditions. Our results show that there is a major dichotomy in the understanding of LC. Studies from some parts of the world, e.g., Africa and South-east Asia, mostly report on LC projects aimed principally at creating larger fields to facilitate management. Studies from other regions, notably from Europe and China, describe LC as a complex form of planning that includes various types of land management measures. The effects of LC projects on land degradation are strongly linked to the type of project. Within the sample of reviewed studies, the effect of LC projects on land degradation was ambivalent, and projects not including land management measures even tended to contribute to land degradation. Conversely, in studies where LC projects involved specific land management measures, LC had a positive effect on most land degradation types. The results of our study indicate that LC projects can help significantly to mitigate land degradation.

1. Introduction

The main goal of village vitality is to create a pair pattern of different elements of rural development, including population, land and industry. As one of the prerequisites, land resources is required to be optimally allocated via land consolidation (LC). As a result, LC makes a significant contribution to resource support, industrial development, and population agglomeration in the context of tackling rural decline (Zhou et al., 2020). A public authority leads the LC process, which is governed by law and used to modify the property structure in rural areas. The purpose of LC is to reallocate parcels between landowners and users to eliminate land fragmentation, allow farm expansion, and/or accomplish other public goals including infrastructure development and environment restoration (Long et al., 2019). LC is a major instrument of rural planning, with roots reaching back to the 18th century (Sklenicka et al., 2017). During the 20th century, LC became widespread across most European countries (Stańczuk-Gałwiaczek et al., 2018; Tang et al., 2017) and in some Asian countries, notably in India (Niroula and Thapa, 2005; Teshome et al., 2016), Thailand and Japan (Sakuma et al., 2001; Uematsu and Ushimaru, 2013; Nguyen and Warr, 2020). In the Central and Eastern European countries, this form of planning became widely used during the post-communist era, beginning in the early 1990s (FAO, 2004; Van Dijk, 2007; Hartvigsen, 2014; Jürgenson, 2016). Recently, there has been an increase in the adoption of land consolidation in some Asian and African regions, in response to pressure to feed increasing populations (Wang et al., 2014; Chapman and Lindenmayer, 2019), and, in some cases, to mitigate environmental degradation (Wang et al., 2014; Zhou et al., 2020; Li and Wang, 2021). In other countries, notably countries in Western Europe, land consolidation is less widely used at the present time than it was in the 20th century (e.g., Hartvigsen, 2014; Hartvigsen, 2015).

The significance attached to land consolidation is evident from the Legal Guide to Land Consolidation, which was recently published by the Food and Agriculture Organization of the United Nations (FAO, 2020). This Guide is primarily based on regulatory practices in Europe, but it explicitly aims to support countries across the world that already have a legal framework or intend to develop such a framework. The Guide also encourages the exchange of good practices between countries. Land

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consolidation, according to the FAO, "is a highly effective land management tool that allows for the improvement of the structure of agricultural holdings and farms, which increases their economic and social efficiency and brings benefits both to right holders as well as to society in general" (FAO, 2020).

One of the fundamental goals of land consolidation is to limit land tenure fragmentation (Dudzińska and Kocur-Bera, 2014; Sklenicka et al., 2014), which is usually achieved by exchanging plots of land to create larger land holdings that are more viable for efficient farming. In countries with extremely small farmland parcels, such as Nepal with an average field size of 0.19 ha (Thapa and Weber, 1990) or Sri Lanka with an average field size of 0.22 ha, creating larger plots of farmland is crucial to maintaining the viability of agriculture (Niroula and Thapa, 2005). However, land consolidation does not always result in larger agricultural blocks in the landscape. Larger blocks would be counter-productive in some cases, for example in many post-communist countries in Central Europe, where overly large blocks of arable land (often over 100 ha in area) contribute to accelerated erosion (Boardman and Poesen, 2007), increased soil compaction (Batey, 2009) loss of biodiversity (Fahrig et al., 2015) and other environmental problems (Skaloš et al., 2014). Paradoxically, these large blocks have resulted from an overly fragmented ownership structure, which makes it impractical or impossible for landowners to farm their own fields. The resulting tenancy-based farming systems tend to result in predatory land management practices (Liu et al., 2013; Skaloš et al., 2014). In such cases, consolidation of land ownership can contribute significantly to the mitigation of this issue.

The approach to land consolidation in individual countries and regions is also widely variable, due to differences in their physical environment (Abubakari et al., 2016) and in socio-economic context, in land management intensity (Kuemmerle et al., 2016), in legislation, and in national traditions (Vitikainen, 2004; Hartvigsen, 2014; FAO, 2020). One particularly sensitive point is the approach to private property. On the one hand, many land consolidation efforts have been abandoned due to concerns about property violation (van den Brink and Molema, 2008; Jürgenson, 2016). On the other hand, some activities which are carried out under the umbrella of land consolidation result in land transactions that can be viewed as unacceptable land expropriation (Teklemariam et al., 2017; Zhou et al., 2019). Land redistribution that takes place within the implementation of land reforms can sometimes have manifestations and impacts similar to those of redistribution due to land consolidation (e.g., Sibanda et al., 2016). In these cases, however, the land management aspects are often minimal or non-existing (e.g., Pacheco, 2009; Elliot et al., 2018).

Individual countries and regions also vary widely in the level of adoption of measures which are not directly connected to the exchange and enlargement of agricultural plots within land consolidation projects. These land management measures include the establishment of field road networks, water management features and erosion control measures (Guo et al., 2015), and, more recently, features which are not immediately related to agricultural production, such as ecological networks (Leń and Król., 2016), land zoning for public utility projects (Dudzińska and Kocur-Bera, 2014), or recreational facilities (Crecente et al., 2002). Countries with a high level of focus on these functions of land consolidation projects generally aim at implementing rural and regional development policies (Sklenicka, 2006; van den Brink and Molema, 2008; Hartvigsen, 2015). In other countries, by contrast, these land management measures have so far been addressed unsystematically (Dudzińska and Kocur-Bera, 2014) or not at all (Nahayo et al., 2016; Asiama et al., 2017).

LC projects are usually funded or co-funded by governments at state, regional and/or local level, and depend on the kind of land management measures implemented by water boards and NGOs (Mohamed et al., 2019). In addition, Mohamed et al. (2019) indicated that co-financing is provided with the purpose of supporting the viability of local agriculture, and, equally importantly, to prevent or mitigate land degradation in farming landscapes. "Land degradation" is a relatively new concept (Johnson and Lewis, 2007; Xie et al., 2020), and research teams utilize a variety of definitions as well as different explanations of the origins and effects of this phenomenon. Some studies consider this phenomenon only as a result of human activities (Norbu, 2003; Ferrara et al., 2020), whilst others factor in the role of natural processes (Nachtergaele et al., 2011; Gryczak et al., 2020). Some studies considered the effect of land degradation on primary production (Singh and Singh, 1995; Wessels et al., 2008; Long et al., 2019), whereas others place emphasis on the environmental and socio-economic dimension of LC (Blake et al., 2018). However, further studies (e.g., Qasim et al., 2011; Mohamed et al., 2019; Ferrara et al., 2020; Hermans and McLeman, 2021) have considered that the main problems contributing to land degradation are associated with socio-economic factors. In this regard, Abu Hammad and Tumeizi (2012) indicated that land degradation is a global phenomenon with natural and socioeconomic causes and effects. They also suggested that socio-economic land degradation necessitates initiatives to raise farmer environmental awareness, as well as environmental standards, rules and regulations, as well as a reduction in land mismanagement. Furthermore, Vu et al. (2014) demonstrated that high levels of land degradation are related to both biophysical and socioeconomic factors. When there is a lot of poverty in vulnerable areas, land degradation is at its worst. The definition offered by Sklenicka et al. (2017), which is used in this review, aims to endorse the standpoints of a wide array of land management stakeholders: "land degradation is the reduction or loss of natural beneficial goods and services, notably primary production services, derived from terrestrial ecosystems". Just as there is no widely-agreed definition of land degradation, there is also no definitive typology of land degradation. Some types, such as water and wind erosion or loss of vegetation, are considered by the majority of studies (e.g., Cowie et al., 2018; Xie et al., 2020; Sherr and Yadav, 1996; Stocking and Murnaghan, 2001). Other types, such as decline in plant species diversity, have been addressed more rarely (Omuto et al., 2014). However, most studies of land degradation address the broader categories of soil physics, soil chemistry, water regime, vegetation (Sherr and Yadav, 1996; Al-Awadhi et al., 2005) and, in some cases, climate (Zuquette et al., 2004).

Land fragmentation is a severe issue, but no significant attempts have been made to address the topic, for a variety of reasons (i.e., ecological and socio-economic causes). It seems that even academics have not concerned themselves sufficiently about land fragmentation. To the best of our knowledge, very few studies have been conducted on land fragmentation. The paper presented here is a theoretical discourse on the effects of LC on land degradation, is an attempt to fill the research gap. It is important to discuss how technical factors affect land degradation because land assets and parcel sizes are steadily declining due to land fragmentation. A cross-regional analysis of the causes of land fragmentation is then presented, addressing the necessity of such an analysis to develop strategic policies for land integration. While the role of LC in counteracting land degradation and in promoting the resilience of farming landscapes is often implicitly assumed (e.g., Zhou et al., 2020), there is a lack of systematic evidence in support of this assumption. To address the current knowledge gap in this area, our study has conducted a systematic review of 93 studies to investigate the effects of land consolidation on land degradation and to supplement the data analysis with maps created in ArcGIS.

2. Materials and methods

2.1. Literature search

The initial literature search was conducted within the Web of Science Core Collection, using the term [(land reform OR land consolidation) AND (land degradat* OR erosion OR soil compaction OR soil crust* OR soil seal* OR sediment* OR silt* OR soil temperature OR soil acid* OR soil alkalin* OR organic matter OR nutrient depletion OR soil contaminat* OR watertable drawdown OR waterlogging OR soil salin* OR

water pollution OR vegetation cover OR species diversity OR alien plant invasion OR air pollution OR desertification)]. This search reflects the terms most frequently used in the scientific literature focusing on land degradation, as summarized in a review by Sklenicka et al. (2017). The results of the search were subsequently limited to the following WOS categories, listed by record count: environmental sciences, environmental studies, ecology, multidisciplinary geosciences, soil science, water resources, environmental engineering, geography, multidisciplinary agriculture, biodiversity conservation, development studies, multidisciplinary sciences, regional urban planning, sociology, agricultural economics policy, agricultural engineering, biology, and interdisciplinary social sciences. The time scope of the study was limited to articles published between January 1990 and November 2022.

The search yielded 679 peer-reviewed studies, from which articles were selected for use in the study based on the following inclusion criteria: (1) land consolidation activities reported in the study resulted in a physical change in the landscape. This means that e.g., policy studies were excluded. (2) The study examined the qualitative and/or quantitative effects of land consolidation activities on land degradation. Finally, we complemented this selection using cross references, adding literature cited by articles from the primary search that met the above criteria. The final selection contains 93 studies from 35 countries across 4 continents.

2.2. Data analysis

For each of the selected studies, we have recorded how the land consolidation process is defined in the relevant country or region and what the reported effects of this process were on various types of land degradation. In most cases, the process of land redistribution towards more economically viable blocks of land was defined as consolidation of land ownership, while several studies described consolidation of land use rights or consolidation of cultivation. In four studies (Elliott et al., 2006; Hadipour et al., 2019; Pacheco, 2009; Sibanda et al., 2016), the term land reform was used for a land redistribution process analogous with land consolidation.

Where the study also mentioned land management measures, these were recorded as well. These measures can be divided into 5 categories, based on their primary purpose, as shown in Table 1.

The classification of the types of land degradation (Tables 2 and 3) was adapted from Sklenicka et al. (2017). One category from this classification (Increased [soil] temperature) has been omitted, as none of the selected studies focused on this issue. On the other hand, as several studies discussed the effect of land consolidation on increased runoff, a decrease in water infiltration and/or retention, edaphon condition, and some of the socio-demographic forms of land degradation (low land tenure security, the farmland rental paradox, and land abandonment), these six categories were added to the original list of land degradation types.

Table 1
Land management measures.

Measures	Descriptions	Example of sources
Field road construction/ improvement within the consolidated area	Organization of plots with straight roads, broader roads, etc.	Lisec and Pintar (2005)
Erosion control	Terracing, construction of erosion control ditches or swales, land use change with the purpose of mitigating soil erosion. etc.	Liu et al. (2013); Nahayo et al. (2016); Jin et al. (2019); Lin et al. (2019)
Nature conservation	The establishment of wildlife habitats and/or conduits.	Shuai et al. (2011); Moyzeová and Kenderessy (2015); Leń and Król (2016)
Water management	The establishment of small waterbodies and polders, the establishment of protective infiltration/buffer strips, stream revitalization, etc.	Najafi (2003); Dumbrovský et al. (2015); Everard (2019)
Land levelling	Soil contamination, farm production, water runoff, etc.	Matsamura and Takeda (2010); Asiama et al. (2017)

This table demonstrates the main measures examined in this study, along with a few examples of sources.

We have recorded the effect of land consolidation on land condition specified by each type of land degradation as either positive, where land degradation has been prevented or mitigated by the land consolidation project; as negative, where the land consolidation project has increased land degradation within the category; or as neutral, where the study mentioned an effect but did not evaluate it or did not provide data for an evaluation.

In the next step, we calculated the overall effect, using the equation:

$$(r = X / (X + Y)) \quad (1)$$

where r is the overall effect, X stands for the number of cases where land consolidation had a positive effect on the type of land degradation, and Y stands for the number of all cases where a positive or negative effect was recorded.

Cases where the value was neutral (N) were not included in this calculation. Where the overall effect values were above 0.5, the effect of land consolidation on the land degradation type was considered positive. Values below or equal to 0.5 were registered as a negative effect, and a value equal to 0.5 was registered as a non-consistent effect. Values close to the endpoints of the interval (0,1) indicated higher consistency of the effect of land consolidation on the land degradation type. Values above or equal to 0.6 indicate a markedly positive effect, whereas values below or equal to 0.4 indicate a markedly negative effect of land consolidation on land degradation.

The overall effect was calculated for three groups of studies: Group 0 includes all studies in the review, Group 1 consists of studies which did not refer to any land management measures as part of the land consolidation project. Group 2 consists of studies in which land consolidation included some land management measures, and Group 3 consists of studies in which land consolidation included erosion control measures, nature conservation measures, or water management measures as the types of land management measures most specifically aimed at mitigating land degradation.

Data analysis was complemented by maps created in ArcGIS. Apart from the overall map showing the geographical distribution of the studies included in the review (Fig. 1Fig. 2Fig. 3), a series of maps were created to depict the influence of land consolidation on specific types of land degradation in individual countries (Fig. 4 and Supplement 1). These maps were created for land degradation types that were the subject of at least 5 studies in at least 3 countries, and where there was a marked overall effect of land consolidation ($r \leq 0.4$ or $r \geq 0.6$) in at least one case, either in the total sample (Table 2, Group 0), or in groups of studies where individual land management measures were implemented (Table 3).

3. Results

3.1. Geographical distribution of the studies

We found 93 studies reporting on the effects of land consolidation activities on land degradation in 35 countries across 4 continents (Fig. 1). The geographical distribution of the studies analysed within this review is very uneven (Fig. 2). More than one half of the studies focus either on China (31.92%) or on the post-communist countries of Central and Eastern Europe (26.07%). 20.14% of the studies were carried out in Asian countries other than China, 10.11% in Western Europe, and 7.43% in Africa. The remaining 4.43% were global studies.

Table 2
Effect of land consolidation on land degradation.

		Group 0 - all studies			Group 1 - no LMM			Group 2 - any LMM			Group 3 - ECM, NCM, WMM		
Components	Land degradation (LD) types	LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect
Soil physics	Water erosion	26	26	0.5	4	8	**0.33**	24	19	0.56	23	14	0.62
	Wind erosion	6	3	**0.67**	1	1	0.00	5	2	0.71	5	1	0.83
	Compaction	3	3	0.50	1	1	0.00	2	2	0.50	1	1	0.00
	Crusting	0	2		0	1	0.00	0	1	0.00	0	1	0.00
	Sealing	0	1		0	1	0.00	0	0		0	0	0.00
	Sedimentation/silting	2	1	**0.67**	0	1	0.00	2	0	0.00	2	0	0.00
Soil chemistry	Acidification	4	3	0.57	2	0	0.00	2	3	0.40	2	2	0.50
	Alkalinization	0	2		0	2	0.00	0	0		0	0	
	Reduction of org. matter	10	6	**0.63**	6	2	**0.75**	5	4	0.56	2	3	0.40
	Nutrient leaching/ depletion	10	8	0.56	4	4	0.50	6	4	0.60	4	2	0.67
	Soil contamination	5	3	**0.62**	0	1	0.00	5	2	0.71	4	2	0.67
Water regime	Water table drawdown	3	1	**0.75**	1	0	0.00	3	1	0.75	3	1	0.75
	Waterlogging	11	1	**0.92**	2	0	0.00	9	0	1	9	0	1
	Salinization	4	3	0.57	1	0	0.00	3	3	0.50	2	2	0.50
	Water pollution	2	0		0	0		2	0	0.00	2	0	0.00
	Increased runoff	11	9	0.55	2	3	**0.40**	10	6	0.62	9	4	0.69
	Decrease in water infilt./ retention	4	2	**0.67**	1	1	0.00	3	1	0.75	3	1	0.75
Vegetation/ landscape	Loss of vegetation cover	11	11	0.5	3	4	0.43	8	7	0.53	8	4	0.67
	Decline in species diversity	9	11	0.45	4	6	**0.40**	7	6	0.54	4	5	0.44
	Alien plant invasion	0	2		0	1	0.00	0	2	0.00	0	1	0.00
	Deteriorated edaphon condition	3	2	0.60	0	0		3	2	0.60	3	2	0.60
Air/climate	Air pollution	1	0		0	0		1	0	0.00	1	0	0.00
	Desertification	0	1		0	0		0	1	0.00	0	1	0.00
Socio-demographic	Low land tenure security	3	0	1	1			2	0		2	0	
	Farmland rental paradox	1	0					1	0		1	0	
	Land abandonment	1	1			1		1	0		1	0	
	TOTAL	130	102	0.56	33	38	0.46	104	66	0.61	91	47	0.66

Table 3
Effect of land management measures on land degradation.

Components	Land degradation (LD) types	Types of land management measures														
		Field road networks			Erosion control measures			Nature conservation measures			Water management measures			Land levelling		
		LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect	LD mitigated	LD increased	Overall effect
Soil physics	Water erosion	12	10	0.55	15	9	0.63	14	8	0.64	17	9	0.65	6	5	0.55
	Wind erosion	2	2	0.50	4	1	0.80	3	1	0.75	4	1	0.80	0	0	
	Compaction	1	0	1	0	1		0	1		1	1		1	2	0.33
	Crusting	0	0		0	1		0	1		0	1		0	1	
	Sealing	0	0		0	0		0	0		0	0		0	0	
	Sedimentation/ silting	1	0	1	2	0		1	0		1	0		1	0	
Soil chemistry	Acidification	2	1	0.67	0	0		1	2	0.33	0	1		2	2	0.50
	Alkalinization	0	0	0.00	0	0		0	0		0	0		0	0	
	Reduction of organic matter	0	2	0.00	1	2	0.33	2	3	0.40	2	2	0.50	4	3	0.57
	Nutrient leaching/ depletion	2	1	0.67	0	1	0.00	2	2	0.50	2	1	067	3	4	0.43
	Soil contamination	1	2	0.33	1	1	0.50	3	1	0.75	3	2	0.60	3	0	1
Water regime	Water table drawdown	1	0	1	2	1	0.67	2	0	1	2	1	0.67	1	0	
	Waterlogging	5	0	1	5	0	1	5	0	1	8	1	0.89	1	0	
	Salinization	1	1		1	0		2	0		2	2	0.50	2	2	0.50
	Water pollution	2	0		1	0		1	0		2	0		1	0	
	Increased runoff	6	5	0.55	6	2	0.75	7	2	0.78	9	3	0.75	4	0	1
	Decrease in water infilt./ retention	2	0		2	1	0.67	3	1	0.75	3	1	0.75	1	1	
Vegetation/ landscape	Loss of vegetation cover	6	5	0.55	6	2	0.75	7	4	0.64	7	3	0.70	5	1	0.83
	Decline in species diversity	2	2	0.50	3	3	0.50	4	3	0.57	4	5	0.44	4	2	0.67
	Alien plant invasion	0	0		0	0		0	0		0	1		0	0	
	Edaphon condition	0	1		1	0	0.33	3	2	0.60	2	2	0.50	1	1	
Air/climate	Air pollution	0	0		1	0		1	0		1	0		0	0	
	Desertification	0	1		0	0		0	0		0	1		0	1	
Socio-demographic	Low land tenure security	1	0		2	0		2			1					
	Farmland rental paradox				1	0		1			1					
	Land abandonment	1	0					1		1	1					
	TOTAL	48	33	0.59	54	27	0.67	65	31	0.68	73	38	0.66	40	25	0.62

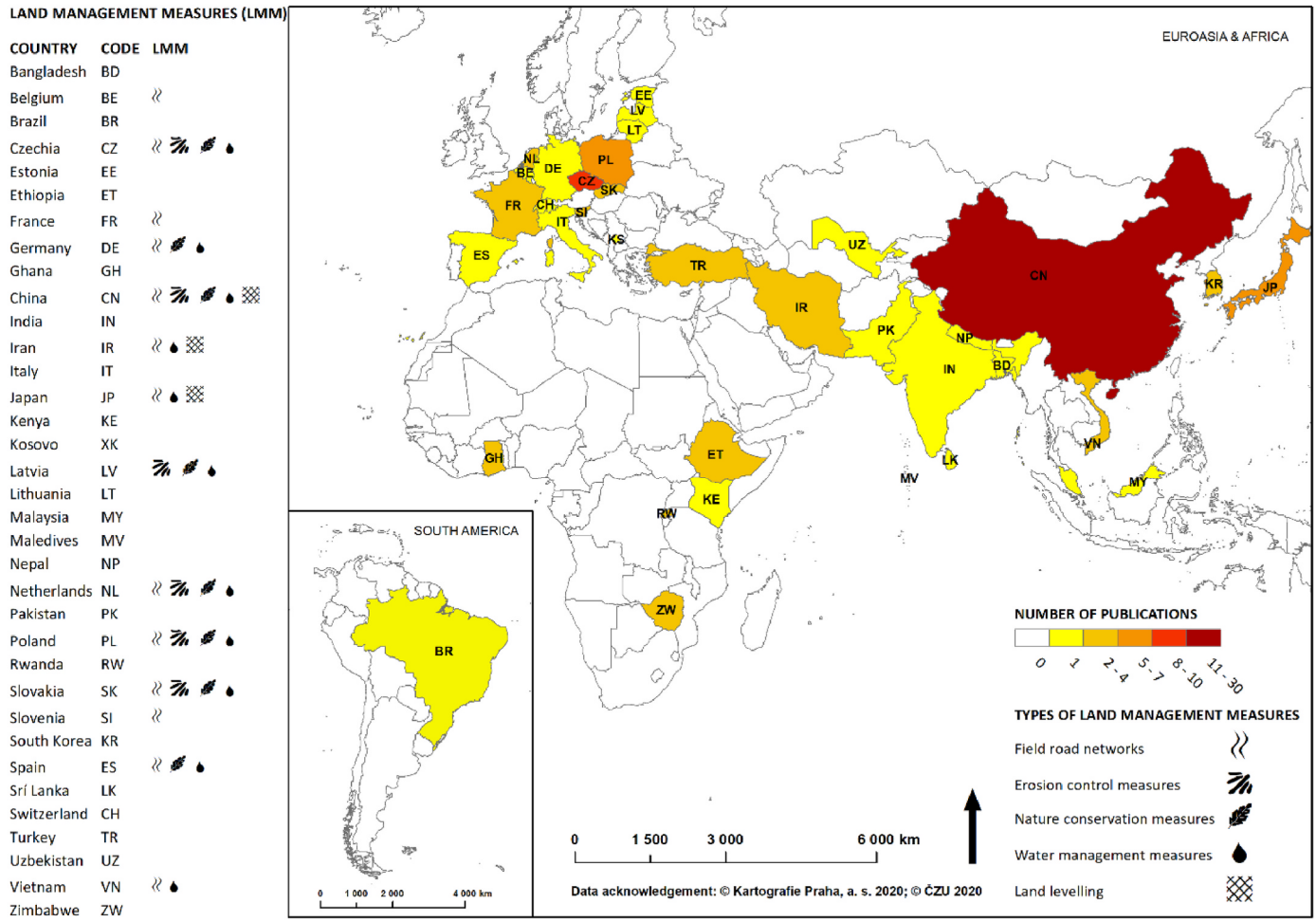

Fig. 1. Geographical distribution of studies of the effects of land consolidation on land degradation. The embedded table lists relevant countries and indicates where land management measures were reported as a part of land consolidation, and the types of land management measures that were reported.

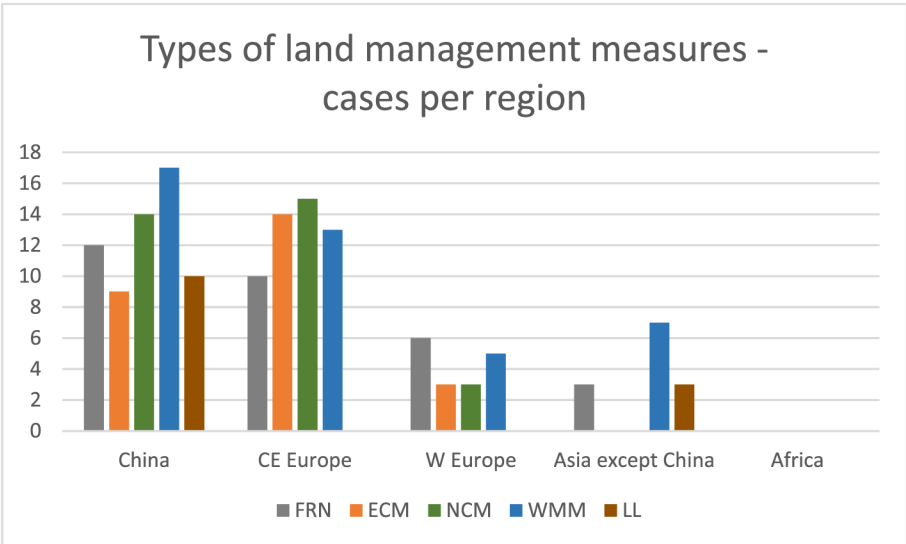

Fig. 2. Numbers of cases in which each group of land management measures was reported as a part of land consolidation projects in each region. China and Central & Eastern Europe (CE Europe) are presented separately from the rest of the countries in their geographical region, as more than 50% of the relevant studies focus on China or on CE Europe. We have found no relevant studies from Australia or from North America, and only one study from South America, which did not mention any land management measures. FRN = field road networks, ECM = erosion control measures, NCM = nature conservation measures, WMM = water management measures, LL = land levelling.

The regions and countries in which land management measures were reported formed an even more limited group (Fig. 2). 43.06% of the reported land management measures were carried out in China, 36.11% in Central and Eastern European countries (CE Europe), 11.81% in Western Europe, and 9.03% in Asian countries other than China. We have found no reports on land management measures implemented within the framework of land consolidation projects in Africa.

The most geographically widespread land management measures

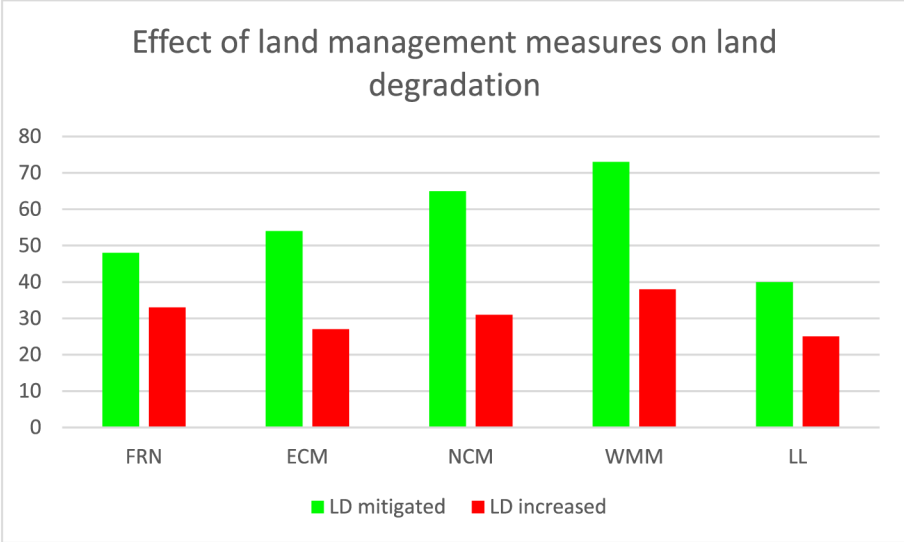

Fig. 3. The effect of land management measures on land degradation - numbers of cases described in relevant studies in which land consolidation projects, including specific land management measures, contributed either to mitigation or to deterioration of land degradation. FRN = field road networks, ECM = erosion control measures, NCM = nature conservation measures, WMM = water management measures, LL = land levelling.

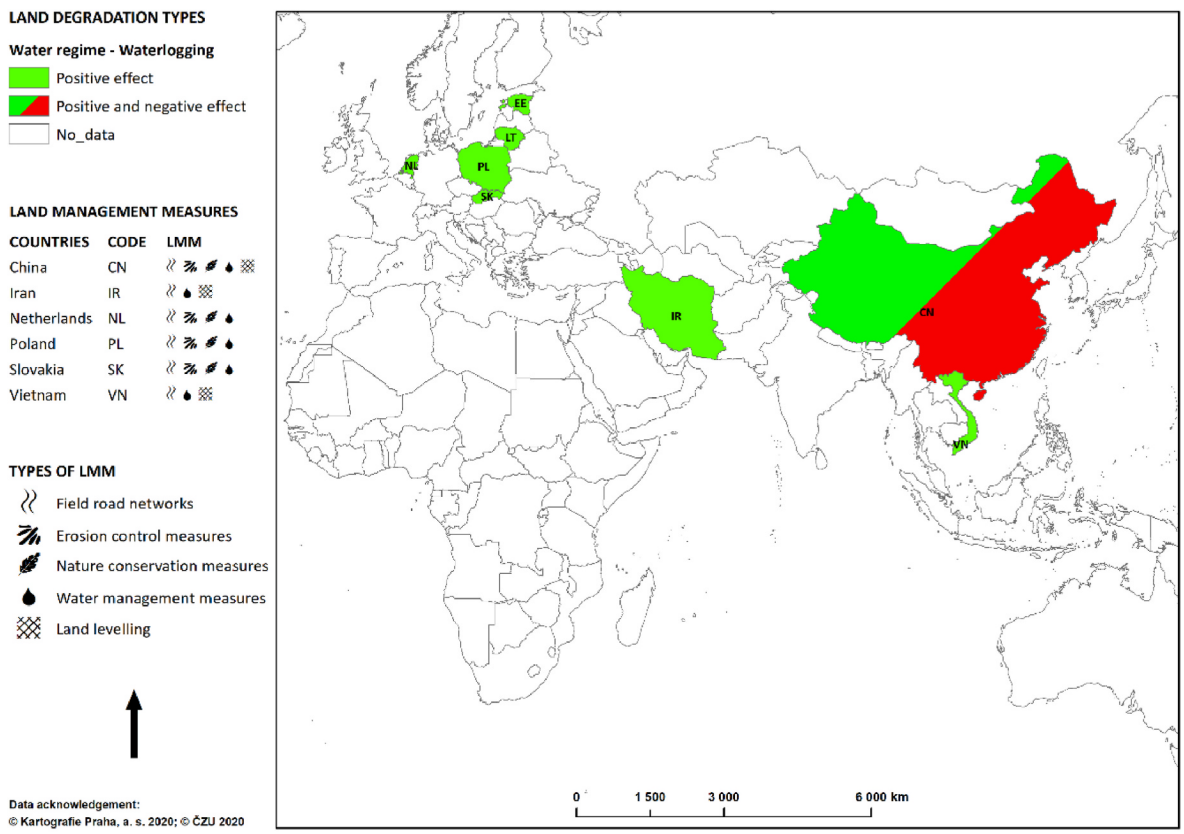

Fig. 4. Effect of land consolidation on waterlogging. In the countries highlighted in green, land consolidation has been reported to mitigate waterlogging. In the countries highlighted in red, land consolidation contributed to an increase in this type of land degradation. In the countries highlighted in red and in green, both positive and negative effects have been found. The embedded table "Land management measures" lists relevant countries in which land management measures were reported as a part of land consolidation, and the types of land management measures. Maps referring to other types of land degradation can be found in Supplement 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

were field road networks (FRN) and water management measures (WMM), which were reported in studies from all monitored regions, with the exception of Africa. The most prominent country in this respect is China (FRN 38.70% of cases and WMM 40.48% of cases), followed by countries in Central and Eastern Europe (FRN 32.26% and WMM 30.95% of cases) and in Western Europe (FRN 19.36% and WMM 11.90%). Erosion control measures (ECM) and nature conservation measures (NCM) were studied in three regions. Central and Eastern

European countries saw the highest incidence (ECM 53.84% and NCM 46.88% of cases), followed by China (ECM 34.62% and NCM 43.75%) and Western Europe (ECM 11.54% and NCM 9.38%). The least widespread land-use measure was land levelling (LL), which was employed in China (76.92%) and other Asian countries (23.08%).

Overall, the most frequent land management measures were water management measures (29.17%, 42 cases), followed by nature conservation (22.22%, 32 cases), field road networks (21.53.0%, 31 cases), erosion control (18.06%, 26 cases) and land levelling (9.03%, 13 cases).

3.2. Effect of land consolidation on land degradation

As shown in Table 2 (Group 0 – all studies), the total number of cases where land consolidation contributed to mitigating land degradation (130 instances, 56%) was slightly higher than the total number of cases in which land consolidation was found to increase land degradation (102 instances, 44%). The overall effect of land consolidation on land degradation r is 0.56, i.e., slightly positive. In Group 0, land consolidation had a marked positive effect ($r \geq 0.6$) on 7 types of land degradation, especially on those types that are related to the water regime.

Table 2 – The effect of land consolidation on land degradation, presents the numbers of cases described in relevant studies in which land consolidation contributed either to mitigating or to increasing specific types of land degradation. The highlighted numbers indicate cases in which three or more studies described a specific type of land degradation and in which the overall effect of land consolidation (cf. Section 2.2) was higher than or equal to 0.6, or lower than or equal to 0.4. Group 0 includes all 93 studies covered in this review; Group 1 contains studies which do not refer to any land management measures (LMM) as being part of the land consolidation process. Group 2 contains studies in which some land management measures were adopted within a land consolidation project, and Group 3 narrows the selection to studies in which land consolidation included erosion control (ECM), nature conservation (NCM), and/or water management (WMM), as measures that are most specifically aimed at mitigating land degradation. The land degradation types and components are adapted from Sklenicka (2016).

Group 1 contains studies that did not refer to any land management measures within the land consolidation process. In this group, many land degradation types were described by fewer than 3 studies. However, in the remaining sample, the results indicate a negative effect of land consolidation on land degradation, with 54% of cases in which land consolidation increased land degradation (38) and 46% of cases in which land degradation was mitigated (33). In three of the four land degradation types with a marked overall effect, the effect was negative.

Group 2 (Table 2) contains studies in which one or more types of land management measures were adopted within the land consolidation project. This group shows a positive effect of land consolidation on land degradation, with 61% of cases in which land consolidation mitigated land degradation (104), and 39% of cases in which land consolidation increased land degradation (66). The affected types of land degradation are similar to the types presented in Group 0. There was a markedly positive effect on seven types of land degradation ($r \geq 6$), and in some cases (e.g., wind erosion or soil contamination) this effect was more pronounced than in Group 0. Interestingly, one land degradation (LD) type (soil acidification), showed a markedly negative effect ($r \leq 4$), although no such effect was observed in Group 0.

Group 3 (Table 2) contains studies in which the land consolidation measures included erosion control, nature conservation, or water management measures as the types of land management measures that are most specifically aimed at mitigating land degradation. In this group, a positive effect of land consolidation on land degradation strongly prevailed, with 66% of cases in which land consolidation mitigated land degradation (91), and 34% of cases in which land consolidation increased land degradation (47). In this group, implemented land consolidation projects had a markedly positive effect ($r \geq 6$) on nine types of land degradation (Table 2). In this group of studies, only one land degradation type, reduction of organic matter, was worsened by land consolidation.

3.2.1. Land management measures

Table 3 and Fig. 3 show the effects on land degradation of land consolidation projects containing specific types of land management measures. Land consolidation projects which included nature conservation measures, erosion control measures and water management measures had a high overall positive effect on land degradation. Projects including nature conservation measures (68% cases of positive influence), contributed to the mitigation of water erosion, wind erosion, soil contamination, waterlogging, increased runoff, decreased water infiltration, loss of vegetation cover and decline in edaphon condition. Negative effects of these projects included increased acidification and reduction of organic matter. Projects including erosion control measures (67% cases of positive influence) contributed to the mitigation of water erosion, wind erosion, water table drawdown, waterlogging, increased runoff, a decrease in water infiltration or retention and loss of vegetation cover. However, these projects also had a negative impact on the amount of organic matter in the soil and on edaphon condition. Projects including water management measures (66% cases of positive influence) had, as could be expected, the most positive impact on the water regime of the landscape (waterlogging, increased runoff and a decrease in water infiltration or retention). These projects also contributed to the mitigation of water erosion, wind erosion, nutrient leaching or depletion, and loss of vegetation cover. Projects with land levelling (62% cases of positive influence) contributed to the mitigation of soil contamination, increased runoff, loss of vegetation cover and a decline in species diversity. Soil compaction tended to increase after these projects had been implemented. Projects with field roads (59% cases of positive influence) had a marked positive effect on acidification, nutrient leaching or depletion and waterlogging.

Table 3. Effect of land management measures on land degradation - numbers of cases described in relevant studies in which land consolidation projects that included specific land management measures contributed either to mitigating or to increasing specific types of land degradation. The highlighted numbers indicate cases where 3 or more studies described a specific type of land degradation and where the overall effect of land consolidation (cf. Section 2.2) was higher than or equal to 0.6, or was lower than or equal to 0.4.

3.2.2. Land degradation types

The majority of studies reviewed here discussed the effect of land consolidation on four groups of land degradation types: those connected with soil physics, soil chemistry, water regime and vegetation. Several studies also discussed land degradation connected with air pollution and socio-demographic factors.

In the larger group of studies, land consolidation projects had the strongest positive effect on land degradation types in connection with the water regime (69% cases of positive influence). In the total sample (Table 2, Group 0), land consolidation had a marked positive effect ($r \geq 0.6$) on waterlogging, on water table drawdown, and on water infiltration or retention. Within the groups of studies that involved erosion control measures, nature conservation measures, water management measures and land levelling, there was an additional positive effect on runoff. Correspondingly, in the group of studies with no land management measures (Table 2, Group 1), land consolidation contributed to a marked increase in runoff.

A positive effect of land consolidation on land degradation types connected with the water regime has been observed especially in China, in the Central and Eastern European countries and in some countries in Western Europe (Fig. 4 and Supplement 1). A negative effect has been observed, mainly in connection with increased runoff (Supplement 1), in Central and Western Europe, Turkey and Iran. The effects of land consolidation on land degradation types connected with soil physics, soil chemistry, and vegetation and landscape show less distinctive

spatial patterns (Supplement 1). In the category of soil physics, the overall effect of land consolidation in the total sample was almost neutral (with 51% cases of positive influence), and there was a marked positive influence on wind erosion and on sedimentation/silting. Wind erosion was also mitigated or reduced in groups of studies that involved erosion control measures, nature conservation measures or water management measures. On the other hand, land levelling contributed to a marked increase in soil compaction.

The most widely discussed type of land degradation in this category, and in the entire study, was water erosion, with 52 studies in the total sample focusing on this topic. Whereas the effect of land consolidation on this type of land degradation was neutral in the total sample ($r = 0.50$), in studies that also included erosion control measures, nature conservation measures and water management measures, land consolidation had a marked positive effect on water erosion ($r = 0.63$, 0.64 and 0.65, respectively). Correspondingly, in the group of studies with no land management measures (Table 2, Group 1), land consolidation contributed markedly to water erosion ($r = 0.33$). In the group of land degradation types connected with soil chemistry, land consolidation had a positive effect in the total sample ($r = 0.57$), and also had a positive effect on some land degradation types (a reduction in organic matter and in soil contamination), with no negative effects. However, within the groups of studies that involved land management measures, the effect on land degradation was rather more negative (see Table 3).

Projects involving nature conservation measures contributed to soil acidification and, along with projects that involved erosion control measures, also contributed to a reduction in organic matter, and projects involving field roads contributed to soil contamination. On the other hand, soil contamination was mitigated or reduced in projects which involved nature conservation measures or land levelling, and field road networks contributed to mitigation or to a decrease in acidification and nutrient leaching or depletion.

The influence of land consolidation on land degradation types connected to vegetation and landscape was slightly negative in the total sample ($r = 0.47$), and there was only one markedly positive effect on edaphon condition. Within the groups of studies that involved land management measures, however, the effect on these land degradation types becomes positive. Projects involving erosion control measures, nature conservation measures, water management measures or land levelling markedly reduced the loss of vegetation cover, and land levelling also contributed to mitigating the decline in species diversity. A positive effect in edaphon condition was reported in studies which involved nature conservation measures, and a negative effect was reported in studies that involved erosion control measures. Correspondingly, in the group of studies with no land management measures (Table 2, Group 1), land consolidation contributed markedly to a loss of vegetation cover and to a decline in species diversity.

Types of land degradation related to air or to climate were very rarely mentioned, and no major overall effects were observed. Six studies mentioned land degradation types linked to socio-demographic factors – low land tenure security, the farmland rental paradox and land abandonment. Land consolidation had an almost uniform positive effect on these types of land degradation ($r = 0.83$). However, the small number of studies involved in this discussion points to a major research gap in this area.

4. Discussion

The results of our study show that there is a dichotomy in the understanding of land consolidation, which is evident both in its historical development and in the different forms that land consolidation projects take in different parts of the world. As the term "land consolidation" suggests, early projects of this kind were aimed principally at creating larger fields for the purposes of easier management. Our results (Fig. 1) show that in some regions, notably in China and in Europe, the paradigm of land consolidation has evolved, and these projects now serve as sustainable land management projects, involving land management measures for erosion control, nature conservation, water management and other purposes. In other regions, notably in Africa and in some Asian countries, land consolidation projects are still only concerned with field enlargement, with no reference to land management measures.

Some contrasting findings of studies included in this review are at least partly due to this dichotomy. On the one hand, land consolidation projects are often presented as a major contribution to the mitigation of land degradation (Li et al., 2015; Jürgenson, 2016). On the other hand, many of the studies reviewed in this article report negative or, at best, neutral effects of land consolidation projects on various types of land degradation. A closer look into the nature of these studies reveals that there is a relation between the nature of land consolidation projects, with or without land management measures, and land degradation.

One of the most frequently discussed negative effects of land consolidation is increased water erosion (Morgan, 2009; Evrard et al., 2010). This effect has been observed mainly in hilly areas (Asiama et al., 2017), especially in the absence of protective measures (Liu et al., 2013). Concerns over wind erosion (Bullard, 2007; Hartvigsen, 2015), increased runoff (Spaan et al., 2006; Liu et al., 2015), loss of vegetation cover (Lisec and Pintar, 2005; Wang and Li, 2019) and loss of species diversity (Uematsu and Ushimaru, 2013; Nam et al., 2019) have often been connected with the loss of landscape vegetation on field boundaries during land consolidation. For example, Bullard (2007) notes that some land consolidation schemes lead to the removal of hedgerows and loss of the benefits that hedgerows provide. These include erosion control, habitats for wildlife, and the production of timber and wild fruits. In some cases, intensification of agricultural practices after land consolidation has also led to reduced organic matter (Dudzińska and Kocur-Bera, 2014; Lirong, 2019), and to nutrient depletion (Li et al., 2015; Nahayo et al., 2016). With a few exceptions (Dudzińska and Kocur-Bera, 2014; Wang and Li, 2019), the land consolidation projects listed above either involved no land management measures at all, or they included only the establishment of field road networks.

Within the group of 93 studies reviewed here, positive effects of land consolidation projects on land degradation were reported in 56% of cases, i.e., only marginally more frequently than negative effects. With the exception of land degradation types connected to the water regime, where the prevailing overall effect was positive, the effect on individual types of land degradation was ambivalent. Based on our results, we conclude that land consolidation projects are almost as likely to contribute to land degradation as they are to mitigate it. This finding need not come as a surprise. Land consolidation projects are often motivated by a desire to introduce agricultural intensification. It is necessary to make preparations for successful, sustainable intensification that will more than compensate for the extra demands on the land that more intensive agriculture implies.

The situation changes when we look at the group of land consolidation projects that included land management measures, especially nature conservation, water management and erosion control measures. Studies where land management measures were part of the land consolidation process reported more favourable outcomes, with land degradation mitigated in 61% of cases, and there was a marked positive effect on most land degradation types where the data was sufficient for analysis. In contrast, land consolidation projects containing no land management measures had a negative effect in 54% of cases, a marked mitigating effect on only one land degradation type, and a marked negative effect on four types. These results emphasize the need for systematic use of land management measures, especially nature conservation, water management and erosion control measures. This approach has been advocated by some authors (e.g., Dudzińska and Kocur-Bera, 2014). However, many studies on the effects of land consolidation, especially those conducted in African countries (Teshome et al., 2016; Asiama et al., 2017), do not mention any measures of this kind.

The results of our study also show that the benefits of specific land

management measures often exceed their primary purpose. Projects that included erosion control measures were the most effective in mitigating water erosion (Sklenička et al., 2009; Shuai et al., 2011) and wind erosion (Spaan et al., 2006; Karásek et al., 2018), and projects that included nature conservation measures contributed more than other projects to mitigating the loss of vegetation cover (Guo et al., 2015). Moreover, projects with nature conservation measures also had a positive effect on wind and water erosion (Zhang et al., 2016; Gečaitė and Jankava, 2017) and on soil contamination (Lin et al., 2019; Wang and Li, 2019). Projects with erosion control measures had a positive impact on vegetation cover (Sklenicka et al., 2017; Zhou et al., 2019). Both types of projects contributed to mitigating increased runoff (Liu et al., 2015; Yurui et al., 2019). Water management measures contributed to the mitigation of increased runoff, wind erosion and water erosion (Mihara, 1996), nutrient leaching or nutrient depletion (Žabenská and Dumbrovský, 2015), and loss of vegetation cover (Zhou et al., 2019). There was a marked positive effect on waterlogging and a marked decrease in water infiltration or retention, both in the total sample and in the groups of studies involving erosion control measures, nature conservation measures (Moyzeová and Kenderessy, 2015; Hanh et al., 2017), and water management measures (Najafi, 2003; Zhang et al., 2016). There was therefore no confirmation of the positive effect of individual measures. However, the overall positive effect of land management measures on the water regime is highlighted by the fact that in the group of studies involving no land management measures, we found no marked positive effects on land degradation types connected with the water regime, and a negative effect on increased runoff.

The effects of projects that involved land levelling and establishing field roads were less consistent. Overall, however, these projects provided more positive effects than projects with no land management measures. Notably, projects that included land levelling tended to mitigate the loss of vegetation cover and the loss of vegetation diversity (Shuai et al., 2011; Liu et al., 2015). The positive effects of land management measures exceeding their primary purpose can be partly attributed to the fact that some studies reported on more than one type of measures. However, it also shows an important synergistic effect between different land management measures. Our results indicate that the mitigating effect on land degradation in land consolidation projects that use a wide range of land management measures can be greater than the sum of the effects of the individual measures. Furthermore, if the effect of some land management measures in such projects is decreased or delayed, e.g. due to extreme weather, other measures can temporarily take over their function.

Although positive effects of land management measures prevailed throughout the study, there were several exceptions to this trend. One of the observed negative effects was the contribution to increased soil compaction of land consolidation projects that involved land levelling (Wang and Li, 2019). Brye (2006) described a similar effect, which was attributed to large-scale manipulation with the soil and to increased use of heavy machinery on farmland during the implementation of land levelling. This potential drawback of land levelling should be taken into account, especially in areas with heavy soils. In such areas, the use of land levelling needs to be carefully considered, despite the potential of land levelling to mitigate other types of land degradation.

Interestingly, both erosion control measures and nature conservation measures tended to have a negative effect on the amount of organic matter in the soil (Wang and Li, 2019; Wu et al., 2019). Erosion control measures also had a negative effect on edaphon condition (Dudzińska and Kocur-Bera, 2014), and nature conservation measures contributed to soil acidification (Lin et al., 2019). This could be because the effect of land consolidation on land degradation was observed a relatively short time after the implementation of nature conservation and soil erosion measures. For example, Wang et al. (Wang and Li, 2019) found a decrease in the amount of organic matter and in pH in the soil immediately after the implementation of gully erosion control measures due to mixing of soil horizons, but this degradation was mitigated after a year of cultivation.

The scope of our study was limited by the fact that relatively few studies have concentrated on the effect of land consolidation on environmental quality, or specifically on land degradation. Only a small number of studies have reported on cases where land consolidation projects resulted in a physical change in the landscape, and have examined the qualitative and/or quantitative effects of land consolidation on land degradation. We have found only 93 studies that met these criteria. The sample size was insufficient for a statistical analysis of the effects of land consolidation on individual types of land degradation. However, the review presented here provides a comprehensive overview of available literature on a topic that has so far not received sufficient attention and that is, we believe, crucial to the development of sustainable land management policies.

5. Conclusion

Land consolidation is often presented as an important tool for the mitigation of land degradation, both in the academic literature and in land development policies. However, there is a lack of systematic evidence in support of these claims. This article has reported on an evaluation of the impact of recent land consolidation efforts on land degradation, and has attempted to establish how the goals and the effects of land consolidation vary between individual countries and regions.

We have found significant differences in the approach to land consolidation in different parts of the world. In some regions (e.g., in Africa and in some Asian countries), land consolidation projects mainly aim at creating larger fields for easier cultivation. Elsewhere, notably in China and in many European countries, land consolidation has evolved into a more complex instrument for sustainable land-use planning that incorporates measures for nature conservation, erosion control, sustainable water management and other land management measures. One of the most important findings of our study is that there is a stark difference between the effects of land consolidation projects with and without land management measures. Many studies have reported on land degradation occurring after the implementation of land consolidation projects that focused only on land redistribution. By contrast, in studies where land consolidation projects involved nature conservation measures, water management measures, or erosion control measures, land degradation was mitigated in 66% of cases, and land consolidation had a positive effect on most land degradation types. It is therefore important to understand this dichotomy in the definition of land consolidation, both for the purposes of academic debate and for more efficient policy formulation.

Our findings indicate that land management measures have a consistent positive effect when they are specifically targeted, and that there is also a notable synergy between the effects of these measures. To make full use of these environmental benefits, land consolidation policies should therefore require each land consolidation project to include measures for nature, soil and water conservation. The effects of land levelling were less consistent, and we recommend that this land management measure should be adopted with caution, especially on heavier soils, where it can lead to soil compaction. The results of this study can also make a contribution to bottom-up farmland conservation. Some studies (e.g., Luz (2000); Hartvigsen (2015)) have indicated that while stakeholders in land consolidation projects, e.g. farmers, appreciate the advantages of field enlargement and a subsequent increase in farming profits, they tend to perceive land management measures as a burden which they either reject or expect to be compensated for. However, our results illustrate the value of these measures in preserving the long-term sustainability of farmland, and they therefore point to a significant additional benefit of land consolidation projects for farmers. This finding could contribute to increased acceptance of land management measures, especially in farming systems with a high level of land tenure security.

Our review has also highlighted some important knowledge gaps that should be addressed by future research. Firstly, there is a general lack of studies focusing on the effects of land consolidation on land degradation, and very few studies have provided a quantitative analysis of these effects. To utilize the potential of land consolidation and similar forms of landscape planning for land conservation, more studies on the effect of land consolidation and land management measures on land degradation need to be carried out in various natural and socio-economic conditions. There is an especially strong need for research on the effect of land consolidation on land degradation types related to soil chemistry. Secondly, our results indicate that a deeper understanding of the long-term development of farmland characteristics after the implementation of land consolidation projects is necessary in order to avoid unintended environmental consequences of these projects. Finally, to utilize the potential of bottom-up farmland conservation, we need to obtain more comprehensive information on the social aspects of land consolidation, particularly in relation to land management measures.

Credit author statement

Conception and design of the study were planned by K. Janečková Molnárová; Data collection and analysis was performed by P. Sklenička; visualization was carried out by I. C. Bohnet; first draft was written by F. Lowther Harris with contribution from A. van den Brink, S. Movahhed Moghaddam, V. Fanta, V. Zástěra and H. Azadi. All authors read and approved the final manuscript.

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Declaration of competing interest

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

Data availability

Data will be made available on request.

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Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2022.117026.

Conflicts of Interest: We hereby confirm that we have no conflict of interest regarding the information presented in the attached article and that the data is publicly available at WOS and other scientific databases.

Code availability: Not applicable.

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Chapter IV – Study 2

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

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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).

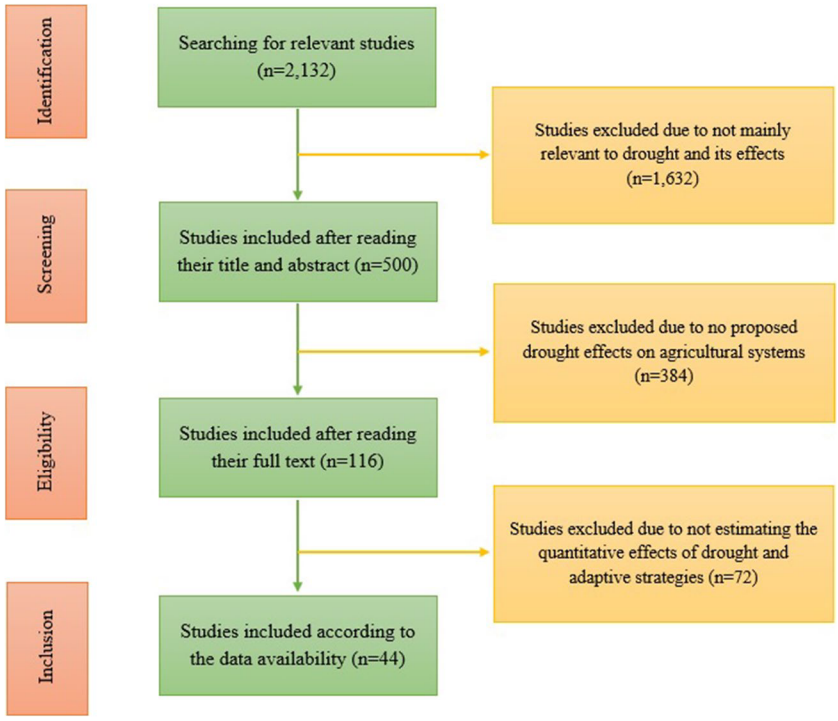

Fig. 1 The process of including or excluding articles. Source: Study's findings

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.

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Chapter V – Study 3

Title: Impacts of land tenure security on the conversion of agricultural land to urban use

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REVIEW ARTICLE OPEN ACCESS

Impacts of Land Tenure Security on the Conversion of Agricultural Land to Urban Use

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Keywords: cadastral assignment | legal status | meta-regression | ownership | tenure type

ABSTRACT

Land tenure security influences several processes relevant to the long-term sustainability of farmland management, including agricultural land conversion to urban use (ALCU). This phenomenon has been illustrated by several studies, mainly on the scale of individual countries. However, there is a noticeable lack of global-scale analyses examining how different aspects of land tenure affect ALCU. To address this gap, we have conducted a meta-analysis of 62 studies that provide quantitative insights into the effects of land tenure variables on ALCU. We used Comprehensive Meta-Analysis (CMA) software to extract data from original articles, including land tenure type (expressed as land farmed by its owner and land farmed by a tenant), legal status (titled land and untitled land), cadastral assignment (designated and not-designated agricultural land), and land ownership (private land and communal land). We have found significant effects of all these aspects of land tenure on ALCU. Land farmed by its owner was the most substantial factor protecting agricultural land from urbanization, with a 3.42% decrease in ALCU. We also observed a 2.97% decrease in ALCU on titled land, a 2.62% decrease on designated agricultural land, and a 1.85% decrease on land that was privately owned. The application of findings and implications for policymakers are substantial: (i) efforts to secure land tenure, especially in underinvested areas, can minimize the degradation of land resources and facilitate better farmland preservation, (ii) the support of owner-operated farming, land titles, private ownership of land, and designated agricultural land is conducive to sustainable farmland management, and (iii) the synergic effect of promoting land tenure security should be utilized to protect agricultural land from conversion to urban uses.

1 | Introduction

Land conversion is defined as a process of change in the character and use of land that is often irreversible (Busko and Szafranska 2018; Ustaoglu and Williams 2017). In most reported cases, land is converted from agricultural to urban use (Soriano et al. 2019), resulting in a global phenomenon that is on a steep rise due to accelerated economic development and population growth (Ma et al. 2020; Kirschner et al. 2022). Given the limited and non-renewable nature of land supply, intense competition arises between agricultural and non-agricultural sectors for land use. Consequently, agricultural land conversion becomes prevalent, markedly diminishing agricultural land availability and threatening food security (Loehr 2012). Ironically, in many countries, especially those where agriculture is the main source of income, agricultural land conversion for urbanization is the prevailing type of land use change (Alphan 2003; Azadi, Barati, Nazari Nooghabi,

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et al. 2022; Das et al. 2022). As local governments or investors in developing countries have realized that urban development is much more affordable on agricultural land than on old urban residential land, there is a greater demand for agricultural land conversion for urbanization (ALCU) (Azadi et al. 2011). In recent years, ALCU has significantly varied by region, but global rates are concerning. According to estimates, between 2000 and 2020, ~4%–7% of agricultural land was converted to urban areas. Asia has one of the highest rates of ALCU, ranging from 6% to 8%, because of rapid urban expansion in countries like China and India. Despite rapid urbanization, Africa has a lower overall percentage of ALCU, because of its considerable rural population and inadequate infrastructure, with conversion rates of 3%–5% for agricultural land. More robust urban planning and land-use laws have resulted in lower conversion rates in Europe, which are about 2%. In North America, ~11 million acres of agricultural land were converted to urban or other non-agricultural uses between 2001 and 2016, making up 2% of all agricultural land on average (Spangler et al. 2020). South America (or Latin America) has mixed rates. In some countries (e.g., Brazil), logging and mining are the primary drivers of agricultural land conversion, but the overall rate of urbanization is about 3% (Cabernard et al. 2024; Ritchie and Roser 2024).

Uncontrolled ALCU, driven by high population density and rapid economic growth (Ho and Lin 2004; Munroe and Müller 2007), has serious consequences for agricultural production, farmers' livelihoods, and the availability of ecosystem goods and services generated by agricultural lands. Rondhi et al. (2018) argued that ALCU is an incentive-driven process used to convert agricultural land, decreasing agricultural production and threatening food security. According to Suu (2009), the disruption of farmers' traditional livelihoods is another significant effect of ALCU. Land conversion has resulted in growing disparity in access to land use rights among farmer households, and especially in the loss of traditional livelihoods, as the majority of the taken land is agricultural land in the densely populated lowland areas near metropolitan centers. At the same time, land tenure security has been recognized in this context as a vital factor in promoting social equality, eradicating poverty, developing sustainable agriculture, and preserving natural resources (Azadi, Barati, Nazari Nooghabi, et al. 2022; Azadi, Burkart, Movahhed Moghaddam, et al. 2022; Nhamo et al. 2022).

Land tenure security is determined by characteristics of land use and ownership, such as private/communal land, land farmed by owner/tenant, titled/untitled land, and designated/non-designated land. In this study, "private land" refers to land owned by an entity or individual, while "communal land" refers to land that is collectively owned or managed by a community or group of people (Gottlieb and Grobovšek 2019; Lipski 2015). It should be noted that there is a third type of land ownership, "public (or state-owned)" land, which is s owned and managed by a government or public authority on behalf of the state (Wily 2011).

However, as none of the relevant studies were concerned with state-owned land, this type of ownership does not occur in our study. Land can be either farmed by its owner (in our study, this owner can be either private or communal), or by a tenant based on a lease contract of variable duration. "Titled land" refers to land with legally recognized ownership documentation, while "untitled land" lacks formal legal titles. The term "designated agricultural land" refers to land that has been formally recognized or assigned for agricultural purposes by land-use planning policies, while "non-designated land" lacks this formal recognition (Dadashpoor and Ahani 2019; Payne 2001, 2004).

A high level of land tenure security stimulates incentives that boost investment and effective use of resources, promoting better access to land (Deininger and Jin 2006; Bennett et al. 2012), and provides official recognition that prevents the illegal conversion of agricultural land for urban purposes (Katusiime and Schütt 2020; Wang et al. 2022). Tenure security also defines the conditions of access to and the use of land resources, including the rights to use, control, and transfer (Deininger and Jin 2006). Land property rights contribute to marginalized groups by increasing food security, economic growth, natural resource management, and agricultural productivity while reducing socio-economic inequalities (Lawry et al. 2017; Tong et al. 2018; Zhu et al. 2020). Secured land tenure has, therefore, been shown to provide support for profitable agriculture that is less environmentally destructive and more economically viable (Bahn et al. 2021; Mishenin et al. 2021).

Several studies (Aguiar et al. 2022; Azadi 2020; Paltasingh et al. 2022; Searchinger et al. 2018; Verburg et al. 2019) have examined the relationship between tenurial arrangements and farm investment and farm efficiency. They have suggested that in this context, tenure security in terms of the formalization of land rights, tenancy arrangements, and transparent ownership status can enhance farm investments. For example, the results of Paltasingh et al. (2022) showed that determining tenancy arrangements will lead to enhanced farm investments. Their results also showed that efficiency is favorably influenced by ownership status in landholding as a whole, demonstrating that owner-operators are more effective than partly tenants and tenants. According to Suchá et al. (2020), land tenure security is essential for facilitating investments in urban agriculture, especially in regions rapidly becoming more urbanized in Soweto, South Africa. Secure land tenure contributes to promoting long-term productivity and food security in urban areas and to increasing farmers' willingness to invest in sustainable agricultural practices. Conversely, insecure land tenure discourages investment, reducing urban agriculture's ability to support livelihoods and environmental sustainability. These results highlight how important it is to incorporate tenure security into urban land-use policies to balance agricultural sustainability and urban growth. Other studies such as Deininger and Ali (2008); Abdulai et al. (2011); Ali et al. (2012), and recent studies such as Byamugisha and Dubosse (2023) in Sub-Saharan Africa and Vu and Goto (2020) in Vietnam have also confirmed the beneficial influence of secure land tenure on farm-level investment decisions. However, infrastructural factors such as inappropriate or fragmented farm size and labor shortages can undermine profitability (Olumba et al. 2021; Sánchez et al. 2022; Stringer et al. 2020).

Evidence shows that land tenure security can promote farm investment. This is achieved by enhancing access to capital,

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as secure land tenure allows farmers to leverage their land as collateral in the credit acquisition process (collateralizable effect), enhancing the claim for land investment return (assurance effect), turning the land trade around from inefficient to efficient (transferability effect), and providing more opportunities for innovation (Bambio and Bouayad Agha 2018). Regarding economic and social benefits, Byamugisha and Dubosse (2023) performed a cost–benefit analysis of land tenure security to examine its transformative potential for agricultural development and poverty alleviation in sub-Saharan Africa. According to their study, secure land tenure encourages long-term investments in sustainable practices and land improvements, which have significant positive social and economic effects.

Overall, the literature emphasizes the beneficial impact of secure land tenure on investment and socio-economic potential (Fenske 2011; Lawry et al. 2017). Investment in land can increase tenure security, but tenure security itself might be strengthened by land investment, especially for informal land rights (Fabusoro et al. 2008; Chigbu et al. 2019; Alemu and Tolossa 2022; Ulukan et al. 2022). Multiple studies (Moor 1996; Fenske 2011) have shown that investment in land benefits from secured land tenure. Other findings underline the fact that wealth impacts, pre-existing tenure institutions, and complementary, holistic institutions all play a role in how land tenure affects land investment (Perera et al. 2018; Gounaridis et al. 2019; Malek and Verburg 2020).

Suu (2009) described a scenario where the land tenure system has yet to recognize an adequate level of private property in relation to land, and where ALCU has consequently become a contentious issue and has frequently disrupted farmers' traditional livelihoods, forcing them to face insecure livelihood prospects. Land-related issues in developing countries are economically, socially, ecologically, technically, culturally, and politically multiplex. Thus, multidisciplinary interventions are necessary (Mdege et al. 2022; Totin et al. 2021) to enhance farm investment. To sum up, land tenure security is firmly rooted in cultural and socio-economic aspects, and dealing with it may necessitate long-term and inclusive approaches.

As shown in Table 1, several review studies have investigated land tenure security in different aspects, with varying levels of focus on its relationship to land conversion. For example, Payne (2001) focused on urban land tenure issues and policy options by analyzing different types of land tenure (e.g., customary, private, public, religious) and property rights. In a similar study, Payne (2004) paid more attention to selected tenure systems such as registered/unregistered and documented/undocumented land and placed them in the global context of land and housing markets. Robinson et al. (2014) performed a meta-analysis to discover the relationship between tropical deforestation and land tenure. To better understand the broad linkages between the form of tenure, security, and forest change, they selected literature that links land tenure and forest outcomes. In a few recent review studies, researchers have investigated various aspects of land tenure security, such as the impact of urbanization expansion on agricultural land (Ayele and Tarekegn 2020), registration and administration of land rights (Valkonen 2021), the human development approach to land tenure security (Abdillah et al. 2022), and the nexus of land tenure, food security, gender, and urbanization (Nchanji et al. 2023). However, there is a research gap in understanding the impacts of land tenure security variables on ALCU at the global level. Furthermore, the effect of converting land use from agriculture to urbanization has been thoroughly studied, but most of the existing literature consists of case studies with different definitions and approaches that concentrate on single countries or regions. Despite their value, these studies have limited generalizability concerning the global factors influencing ALCU. Moreover, until now, there has been little investigation into the synthesis of findings through meta-analyses, which are often restricted to specific forms of tenure security or geographical contexts. Therefore, to the best of our knowledge, no study has yet systematically examined the quantitative impacts of various facets of land tenure security (such as ownership type, land titles, and cadastral designation) on ALCU globally, using a meta-regression approach. This study's methodological approach is novel, as it uses meta-regression to aggregate quantitative data from multiple studies and determine the specific impacts of various land tenure aspects on ALCU. In addition to offering a global perspective, the study offers policy-relevant insights that could direct regulatory frameworks and land use planning efforts to protect agricultural land and minimize the negative social and environmental effects of ALCU.

Therefore, to address the research gap and to derive a better understanding of the links between land tenure security and agricultural land conversion, this study aimed to (i) make a critical review of articles that have examined land tenure security affecting ALCU, (ii) explore the patterns of land tenure security linked to ALCU, and (iii) provide recommendations for strengthening global land tenure security in the future.

2 | Methodology

Our study has used a meta-analysis (Vesco et al. 2020; Woodcock et al. 2014) to synthesize the impacts of land tenure variables on ALCU on a global scale. Quantitative results are synthesized to examine the validity of the effects obtained in the original articles on a larger scale. The effects were estimated through a meta-regression in which multiple variables interact (Röver and Friede 2023). Table 2 summarizes the land tenure security variables used in this meta-regression. Each of the studied land tenure security variables, that is, Land ownership, Legal status, Tenure type, and Cadastral assignment, assumed values that reflect the dichotomic categories used in the original studies.

2.1 | Data Collection and Inclusion and Exclusion Criteria

During an initial search (Pigott and Polanin 2020), several databases including Web of Science, ScienceDirect, Springer, Oxford University Press, ProQuest, and SID were thoroughly investigated to identify original studies. The time scope for the studies was between the years 2000 and 2023. The main keywords used to obtain data were "land tenure," "land tenure security," "private land," "communal land," "titled land," "untitled land," "land farmed by owner," "land farmed by tenant," "designated agricultural land," and "agricultural land conversion." Overall, 4236 original articles were found in the initial search.

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TABLE 1 | Several examples of review studies conducted by researchers worldwide.

	Variables									
	Ownership		Legal status		Tenure type		Cadastral assignment			
Study	Private land	Communal land	Titled land	Untitled land	Land farmed by owner	Land farmed by tenant	Designated agricultural land	Not-designated agricultural land	ALCU	Case study
Payne (2001)	X	X								Global
Payne (2004)		X	X	X						Global
Robinson et al. (2014)	X	X	X							Continental
Robinson et al. (2018)	X	X	X							Global
Kenfack Essougong and Teguia (2019)	X	X					X	X	X	Regional
Alban Singirankabo and Willem Ertsen (2020)			X	X	X	X	X	X		Global
Ayele and Tarekegn (2020)		X			X	X			X	National
Valkonen (2021)	X	X	X	X						Global
Abdillah et al. (2022)			X	X						Regional
Nchanji et al. (2023)	X	X	X						X	Regional

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TABLE 2 | Definition of the main land tenure security variables.

Variables	Values	Definition
Ownership	Private land	Land owned by individuals, families, corporations, or other private entities
	Communal land	Land owned or managed collectively by a community or group
Legal status	Titled land	Land registered in the real estate register
	Untitled land	Land not registered in the real estate register
Tenure type	Land farmed by owner	Land farmed by individuals, families, corporations, or other private entities who own this land
	Land farmed by tenant	Land farmed by individuals, families, corporations, or other private entities who rent this land from other subjects
Cadastral assignment	Designated agricultural land	Land designated in the cadastral system for agricultural purposes
	Not-designated agricultural land	Land not designated in the cadastral system but used for agricultural purposes

The second step was to select articles focusing on the impact of land tenure security on ALCU in their titles and abstracts, which resulted in 1252 articles. In the third step, we selected papers written in English that contained quantitative data on the land tenure security impacts and its variables (as defined in Table 2) on ALCU. This step resulted in the selection of 93 journal articles. In the fourth step, the effect sizes were considered among different aspects of land tenure security on ALCU in the original articles, to exclude papers that failed to provide the necessary data to calculate percentage differences. We calculated the percentage differences between land tenure security variables for all outcome values to obtain uniform effect sizes, as we go into further detail in the following section. Overall, in this step, the total number of original articles was narrowed down to 62. In November 2023, the literature search was completed.

2.2 | Data Processing, Extraction, and Combination

In this study, ALCU was the dependent variable, and the independent variables were land ownership, legal status, tenure type, and cadastral assignment. This meta-analysis focused on the effect of land tenure security and its variables on ALCU.

Individual studies measured outcome variables in different units (e.g., yields are measured in tons or kg per acre or ha; income can be measured in local currency, US dollars, or percentage increase). Therefore, to have uniform effect sizes and to prevent the problem of heterogeneity, which frequently occurs in meta-analysis studies (Meemken 2020), the percentage differences between variables were considered as the unit. Percentage differences have a unique benefit over other standardized effect size measures in that they can be calculated without considering variance. This feature is particularly useful when dealing with studies where variance information is frequently omitted. Furthermore, percentage differences are favored in this context due to their simplicity and ease of comprehension (Klümper and Qaim 2014). Weights are assigned to individual results based on the sample size of their respective studies, while cluster corrections are also applied for observations from shared datasets. This approach allows us to derive the average mean and median effect sizes. In this study, the median effects are estimated using quantile regressions.

The variability in the methodologies of the analyzed articles, which is a significant challenge of meta-analysis studies (Vesco et al. 2020), was factored into the analysis via several additional variables such as time, space, type of article, and methodology applied. Then, the variables were categorized as continuous (i.e., time) or dummy (i.e., space, type of article, and methodology applied). To perform the analysis, a dummy variable was assigned a value of 1 if it showed the defined variable (e.g., study area); otherwise, it was assigned a value of 0.

The coefficient of determination, or R^2, is a statistical criterion for determining data accuracy, since it reflects the percentage of variance in the dependent variable based on the independent variables defined in the regression model. Using Comprehensive Meta-Analysis (CMA) software, we extracted the data from original articles that analyzed the quantitative impact of land tenure security on ALCU. Overall, the results presented in the original articles were summarized using a meta-analysis of statistical methods, and the mean effects of land tenure security on ALCU were estimated by integrating the effect sizes from the output of the collected articles.

3 | Results

3.1 | Descriptive Statistics

The original articles capture different aspects of land tenure, including ownership, legal status, tenure type, and cadastral assignment (Table 3). Among the selected articles, most of the studies focused on land ownership (24 articles). The other classes of legal status, tenure type, and cadastral assignment were studied in 16, 14, and 8 articles, respectively.

Figure 1 displays the spatial distribution of the 62 original studies. Research for the articles was done across 17 different countries on the continents of Africa, South America, North America, Asia,

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Europe, and Oceania. The largest proportion of the studies—20 articles, or 32.2%—were performed in Asia; the most widely represented country was China (10 articles, or 16.1%). Four original articles studied several countries at once, while the rest of the original articles focused on only one country.

Figure 2 illustrates the temporal trend of the studies. There is an increasing trend in numbers from old studies to more recent studies. Between 2000 and 2003, only 2 studies were performed, and between 2004 and 2007, the number was 8. The largest number of studies (17 articles; 27.4%) was conducted between 2016 and 2019. As shown in Figure 2, the number of studies on the impact of land tenure security on ALCU has increased considerably since 2015, highlighting the increasing focus on this topic.

TABLE 3 | Overview of the original articles focusing on land tenure features.

Land tenure	Number of original articles
Ownership	24
Legal status	16
Tenure type	14
Cadastral assignment	8

Source: Study findings.

3.2 | Meta-Regressions

Results of meta-regression in CMA are listed in Table 4 and Figure 3. The results show that ALCU has been affected by all studied land tenure variables: land ownership, legal status, tenure type, and cadastral assignment. More specifically, ALCU has been found to occur significantly less on private land (mean effect: −1.86, $p \leq 0.01$), on titled land (mean effect: −2.97, $p \leq 0.01$), on land farmed by its owner (mean effect: −3.42, $p \leq 0.01$), and on designated agricultural land (mean effect: −2.62, $p \leq 0.01$). The opposite parts of land tenure security variable dichotomies, as mentioned in the original articles, did not have a significant effect on ALCU. The variables included communal land (mean effect: 1.92), untitled land (mean effect: 7.96), land farmed by tenants (mean effect: 2.64), and not-designated agricultural land (mean effect: 4.47). The highly significant impacts of land tenure variables on ALCU, illustrated in Figure 3, are the most relevant results of this study.

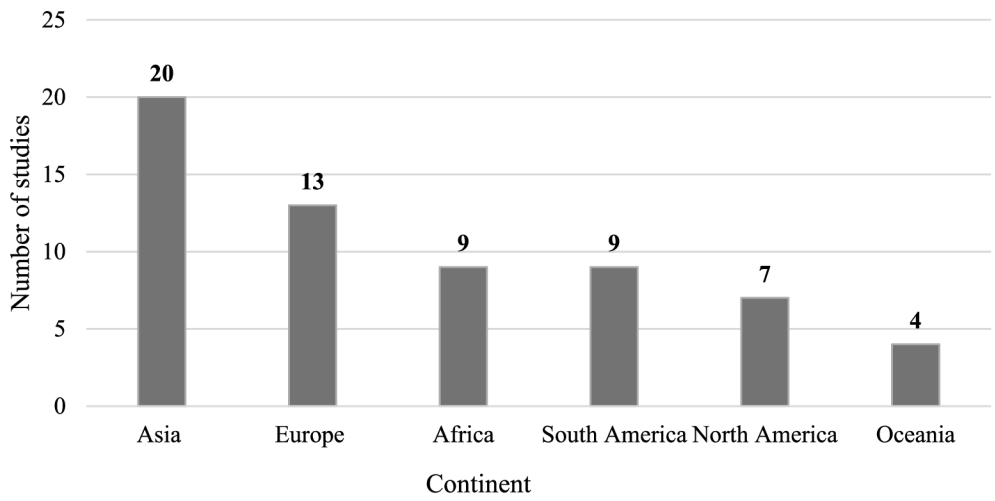

FIGURE 1 | The spatial distribution in different continents *Source:* Study findings.

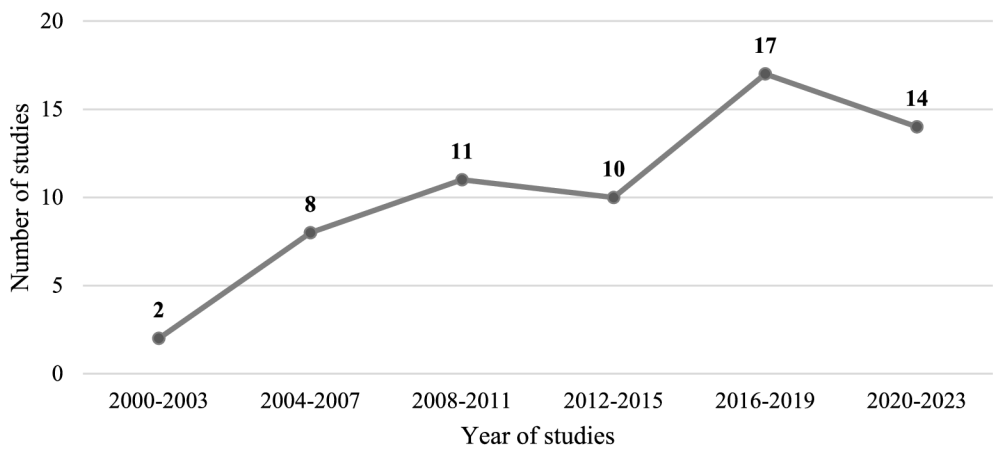

FIGURE 2 | The temporal trend of the studies *Source:* Study findings.

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TABLE 4 | Results of meta-regression in CMA.

		Land use impacts		
		ALCU		
Variable	**Values**	**Mean effect**	**Median effect**	**Standard error**
Ownership	Private land	−1.86***	−1.96***	0.25
	Communal land	1.92	2.05	1.62
Legal status	Titled land	−2.97***	−3.20***	4.92
	Untitled land	7.96	7.10	0.40
Tenure type	Land farmed by owner	−3.42**	−3.22**	1.83
	Land farmed by tenant	2.64	2.27	1.89
Cadastral assignment	Designated agricultural land	−2.62***	−2.66***	0.52
	Not-designated agricultural land	4.47	3.20	3.20
Time	Year of data collection	0.35	0.20	0.76
Space	Africa	−1.39	−0.14	1.41
	South America	4.16**	3.14**	1.94
	North America	3.25	2.11	2.01
	Asia	1.46	0.32	1.09
	Europe	−0.80	−0.21	1.42
	Oceania	−0.71	−0.06	2.06

Note: ** and *** indicate $p \leq 0.05$ and $p \leq 0.01$, respectively. The results of CMA evaluated the following results for other additional variables: article type: 0.89%—Methods to cope with heterogeneity: −2.24%. R^2 is 72%, which shows the ratio of the variance of the impacts that were explained by including additional variables in meta-regressions.
Source: Study findings.

Considering the temporal patterns, with a 1-year increase in data collection time, the conversion of agricultural land to urban use increased by ~0.3%. Focusing on different continents, the levels of ALCU were significantly higher in studies conducted in South America (mean: 4.2, $p \leq 0.05$). In North America and Asia, the ALCU levels tended to be above average (mean effect: 3.25 and 1.46, respectively, not significant), while in Africa, Europe, and Oceania, ALCU occurred less frequently (mean effect: −1.39, −0.80, and −0.71, respectively, not significant).

4 | Discussion

To assess the impacts of land tenure and its variables on ALCU, the present study applied a meta-analysis of 62 studies published between 2000 and 2023. The study aimed to fill a research gap in the understanding of the principles underlying the effect of land tenure variables on ALCU, particularly at the global level.

4.1 | The Effect of Land Tenure Security Variables on ALCU

The findings of our study show that all studied land tenure security variables, that is, Land ownership, Legal status, Tenure type, and cadastral assignment, have significant effects on ALCU. Specifically, mean ALCU decreased by 3.42% on land farmed by its owner, by 2.97% on titled land, by 2.62% on designated agricultural land, and by 1.86% on private land, compared with the overall sample. While this is the first study to make a comprehensive assessment of the effects of multiple land tenure security variables on ALCU, its results are in line with studies focusing on the impact of these variables on the sustainability of farming and land management. Where farming systems lack environmental, social, or economic sustainability, the likelihood of farmland abandonment and its conversion to other uses increases (Movahedi et al. 2021). A systematic review by Higgins et al. (2018) on rural land tenure security showed its significant impacts on environmental conservation, agricultural productivity, and socio-economic outcomes. Similar to our findings, their results demonstrated that increased tenure security encourages owner-operated farming to invest in long-term improvements. However, their review also emphasized how differences in policy implementation and sociopolitical contexts lead to disparities in benefits.

Several studies have confirmed the benefits of land being farmed by its owners (also referred to as owner-operated farming), as opposed to land being farmed by tenants. For example, Sklenicka et al. (2015) found that farming owners adopted soil conservation measures to a significantly higher degree than farming tenants. Potthoff and Dramstad (2023) note that renting farmland can lead to less sustainable decisions, and they recommend land reallocation. The benefits of owner-operated farming

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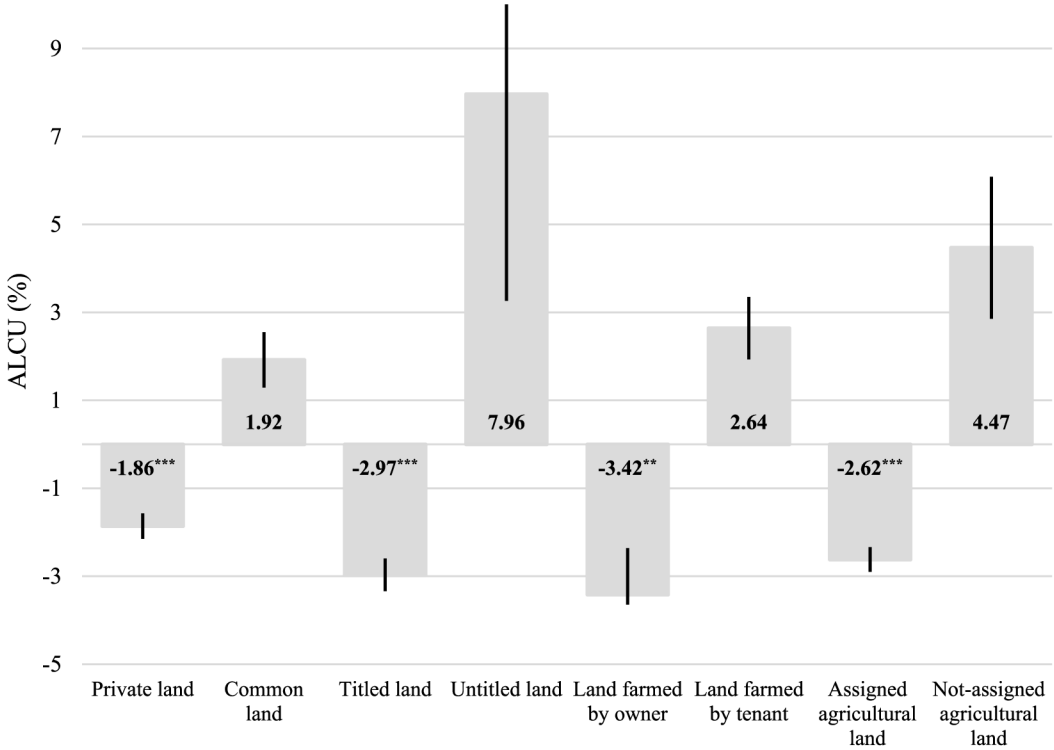

FIGURE 3 | The impacts of land tenure variables on ALCU in the mean with standard deviations. *Source:* Study findings. ** and *** indicate $p \leq 0.05$ and $p \leq 0.01$, respectively.

to sustainable land management are consistently confirmed by studies from different countries with various natural conditions and legal and political environments (Hu 1997; Praneetvatakul et al. 2001). In this respect, our study has contributed to a body of literature supporting the introduction of policy and fiscal measures to promote owner-operated farming to facilitate the sustainable management of land and other vital resources.

Similarly, farming on titled land has been illustrated to lead to more sustainable land use than farming on untitled land (Mutangadura 2007; Tatsvarei et al. 2018). Charoenratana and Shinohara (2018) demonstrate that farmers' livelihoods and, therefore, the social and economic sustainability of farming depend on whether and how their farmland is titled. Their results showed that plots, where farmers have formal land titles, are cultivated more intensively and have higher productivity than plots without titles. Wannasai and Shrestha's (2008) findings revealed that the reduction in the likelihood of land conversion to non-agricultural uses is linked to households with titled land being more likely to invest in sustainable land management practices in the Prasae Watershed, Thailand. To achieve sustainable land use outcomes, the study highlighted the importance of tailored land policies that address both tenure security and household dynamics. Improving farmers' access to land, better recognition of customary land rights, and more effective protection of land without recognized claims could be helpful to policy responses. Byamugisha and Dubosse (2023) demonstrate the institutional and financial difficulties in putting tenure security reforms into practice, especially in areas with fragmented governance systems. These results imply that improving tenure security is crucial for tackling broader development issues and promoting economic resilience.

As confirmed by several studies (Besley et al. 2016; Szuma 2016), due to market dynamics, regulatory protections, land use policies, and community engagement aimed at preserving agricultural resources and landscapes, designated agricultural land generally experiences lower conversion rates to urban uses than non-designated agricultural land.

Discussing the lower susceptibility of private agricultural land to conversion to urban areas, given the fact that private land is typically owned and managed by individuals or organizations with the power to decide how it will be used and developed, Lipski (2015) stated that private agricultural land can satisfy farmers' demand for land plots and interest in investing in their farms. In this sense, Nguyen et al. (2016) indicated that in countries with private agricultural land ownership, land conversion occurs through agreements between local governments and investors, or it takes place voluntarily, aligned with landowners' preferences. However, in such land ownership regimes, development permits and land use planning policies can play a significant role in determining the possibility of converting private farmland to urban areas.

The case studies indicate that most of the studied spatiotemporal variables did not have a significant effect on ALCU, apart from the higher occurrence of ALCU in South America (4.16%). According to Silva and Vergara-Perucich (2021) economic, socio-demographic, cultural, and political forces define the primary causes of ALCU in Latin America. In the case of Santiago de Chile, the determinants are context-based, such as enhancements in regional connectivity, deficiencies in agricultural land use planning and regulations, and uncertainties regarding the consequences of urban development. Pauchard

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and Barbosa (2013) illustrate the abandonment of poor soils, low levels of governance, and limited information on urban development strategies as the main contributors to ALCU in South America.

4.2 | Methods and Challenges in Increasing Land Tenure Security

There are two main approaches that can be utilized in efforts to increase land tenure security and thereby limit ALCU. First, efficient land use and planning policies can greatly contribute to a higher level of land tenure security. For example, land consolidation plans, which aim to reallocate farmland within a cadastre or similar land-management unit, can often contribute to an increase in owner-operated farming in the area, as they create plots of land that are more viable for this type of farming (Zhang and Ye 2024). However, it is important to note that while in many parts of the world, land consolidation efficiently combats land tenure insecurity and land degradation (Jürgenson 2016; Li et al. 2015) land consolidation methods employed in other countries can contribute to deterioration in livelihoods and environmental conditions (Asiama et al. 2017; Wang and Li 2019). Similarly, efficient cadastre systems are key to providing and preserving safe titles to farmland (Fisher and Whittal 2020). However, in some cases, especially in developing economies, cadastral systems have been recorded to facilitate higher inequality in the distribution of land resources (Kapstein 2018). Analogically, spatial planning has been noted to be an effective method for securing farmland designation (Chen et al. 2021) and a method facilitating faster conversion of farmland to non-agricultural uses (Xu et al. 2015). To be effective in increasing land tenure security and preventing ALCU, planning policies have to be informed by high-quality research, and, equally importantly, they need to be inclusive and based on democratic planning principles, as defined, for example, by Bruns and Hennecke (2022).

Second, while the long-term benefits of increasing land tenure security and preventing ALCU are often well understood, short-term economic interests may prevail (e.g., Fraser 2004). Therefore, a well-balanced system of economic incentives, both positive and negative, can significantly contribute to the long-term sustainability of land-use systems by supporting owner-operated farming, land titles, private ownership of land, and agricultural land designation.

5 | Conclusion

The results of this study show that land tenure security can be effective in preventing undesirable changes in land use in all parts of the world and the associated harmful impacts on farming communities and the environment. Land tenure security should, therefore, be preserved and promoted by land use and planning policies, as well as by economic incentives. Regulatory protection should include accessible land titling programs, simplified land registration procedures, and frameworks legally prioritizing agricultural use in specific regions. However, as mentioned earlier, fragmented regulatory frameworks and limited institutional capacity may compromise efforts to secure land tenure. To address this, there should be a central coordinating body to simplify communications and capacity-building efforts to enforce tenure regulations.

The main implications of our results for land use policymaking and other regulatory activities can be summed up in the following three points:

1. Land tenure security plays a significant role in preserving agricultural land and its functions. Therefore, ensuring this security in present and future land use systems is one of the most critical tasks of land use policy. Especially in underinvested areas, preserving and enhancing land tenure security is vital in reducing the degradation of land resources. Therefore, directly involving local communities in land governance is necessary in such areas to promote tenure security through community engagement. Also, to ensure policies consistent with local practices and requirements, it is necessary to include community-led resource management programs, participatory land mapping, and regular consultations in land use policy programs. However, in underinvested areas, financial limitations usually make it impossible to implement and enforce land tenure security policies. To tackle this, there is a need for resource allocation and external financial support in maintaining effective land tenure measures.
2. Each of the four land tenure security variables examined in this study has the potential to reduce the level of ALCU significantly. Land use policies need to focus on promoting owner-operated farming, land titles, private ownership of land, and agricultural land designation as practices conducive to the preservation of agricultural land and the prevention of detrimental social and environmental effects associated with ALCU. Our results also emphasize the prominent role of owner-operated farming as the most substantial factor preventing ALCU.
3. The findings of this study add a new aspect to the body of literature discussing the role of land tenure security and its various forms in ensuring the economic, social, and environmental sustainability of farmland management. In accordance with the results of our study, owner-operated farming, land titles, private ownership of land, and designated agricultural land have been found to significantly promote the sustainability of farming systems.

Overall, our study contributes to the understanding of the impacts of land tenure security on ALCU at the global level by applying a robust literature review and meta-regression method. However, better knowledge of land tenure security variables and their impacts may not lead to better protection of agricultural land from conversion to urban uses due to barriers such as a lack of institutional support and limited financial resources. We therefore suggest that future research should look into the extent and the consequences of land degradation resulting from agricultural land conversion, and also into ways of mitigating land degradation using land tenure security strategies. Future research should also investigate the allocation and utilization of financial resources in this field, and the effectiveness of existing institutional frameworks and policies addressing land tenure security.

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Author Contributions

Saghi Movahhed Moghaddam: conceptualization, formal analysis, data curation, writing original, writing review and editing. **Hossein Azadi:** formal analysis, validation, writing review and editing. **Petr Sklenička:** funding acquisition, project administration, writing review and editing. **Kristina Janečková:** funding acquisition, project administration, supervision, writing review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Chapter VI – Discussion and Summary

The following section presents the overall discussion and conclusion of the dissertation. This chapter aims to link individual studies and explore the most interesting aspects of this research, providing insight into how the results are interpreted and suggesting potential future directions.

Significant threats to global agricultural sustainability, food security, and environmental preservation are rooted in interconnected challenges such as land degradation, drought, and agricultural land conversion to urban use. Thus, it is essential to address these challenges through an understanding of the underlying causes of these issues as well as the potential for sustainable farmland management approaches. Three studies' results are combined in this discussion to offer a thorough understanding of the issue. The first study assesses how land consolidation affects land degradation, highlighting the different results based on whether land management measures are included. The second study investigates how drought affects various agricultural systems on socioeconomic and environmental aspects. The third study analyzes the relationship between land tenure security and agricultural land conversion to urban use (ALCU). When taken as a whole, these studies offer insightful information about sustainable farmland management approaches and their contributions to environmental preservation and global food systems as discussed in the following:

Contextual variability in land consolidation outcomes

Europe and China vs. Africa and Southeast Asia

Farmland consolidation aims to integrate small land parcels into larger land tracts, optimize the size of land parcels, eliminate mosaic land ownership, improve the efficiency of agricultural machinery use, and develop social and biophysical infrastructure (Sagaydak and Sagaydak, 2022). Numerous scientific studies, including Biarel et al. (1992), Thomas (2006), Sky (2015), Backman (2016), Jin et al. (2017), Zhou and Cao (2020), Ntihinyurwa and de Vries (2020) and others address the land consolidation issue in agriculture and its contribution to minimizing land degradation.

The main goal of farmland land consolidation projects in Southeast Asia and Africa is to expand field sizes to promote farming efficiency and mechanization (Asiama et al., 2017). However, if ecological factors are not considered, this limited focus may inadvertently exacerbate land degradation by accelerating soil erosion, nutrient depletion, and vegetation loss. When landholdings are divided into parcels, their size gradually decreases. This process becomes more challenging when a fragmented landholding is divided into multiple parcels simultaneously. This is common in South

Asia and is explained by the equal division of various land parcel qualities. Due to the long-standing custom of dividing up suitable and poor-quality land parcels among household heirs, especially when they separate, land fragmentation is occurring at a very high rate in many Southeast Asian countries where a landholding consists of multiple parcels of land with different biophysical characteristics, such as soil quality and moisture condition (Nguyen and Warr, 2020).

In **Study 1**, by analyzing the results of 93 articles, the effects of land consolidation projects implemented under different natural and socio-economic conditions have been examined. Based on the findings, studies from Africa and Southeast Asia mostly report on land consolidation projects aimed at creating larger fields to facilitate management. This is consistent with Niroula and Thapa's (2005) study in South Asia found that landholdings and parcels are becoming more fragmented, slowing agricultural development and accelerating degradation. Their research showed that farmers are discouraged from implementing agricultural innovations due to the fragmentation of small landholdings and small land parcels, which impacts both land conservation and economic gain. They concluded that the consolidation of small landholdings and land parcels is necessary for the agricultural development of South Asian nations. This entails eliminating the current circumstances of extreme smallness and high fragmentation, which is challenging to accomplish. Similarly, Nguyen and Warr's (2020) findings showed that land consolidation contributes to economic growth by raising farm income, releasing more farm labor to off-farm sectors, and increasing off-farm income. Therefore, enhancing farm productivity, at least from land consolidation, will encourage the growth of the off-farm economy and the economic diversification of rural households, supporting government policy goals.

Regarding African countries, **Study 1** found that land consolidation projects are still only concerned with field enlargement, with no reference to land management measures. It shows that land management measures are barely implemented in African countries. This aligns with the study by Biarel et al. (1992), who investigated the detrimental economic impact of farm fragmentation in African countries. They discovered that one significant characteristic of less developed agricultural systems is the presence of fragmented landholdings. According to their findings, there are several costs of fragmentation, namely decreased labor productivity and higher input and output transportation costs resulting from longer travel times between fields; negative externalities include fewer opportunities for irrigation and soil conservation investments, as well as the loss of land for access routes and boundaries; and a higher likelihood of conflicts. Given these costs, several land reform initiatives have attempted to enforce—or at the very least, provide subsidies for—holdings consolidation. These policies are predicated on the idea that land consolidation can boost agricultural output and social welfare, and that fragmentation is inherently inefficient. Furthermore, a more recent study by Asiama et al. (2017) investigated the potential of land consolidation to address land fragmentation in Sub-Saharan Africa.

They argued that the transfer of European strategies without sufficient local consideration in the planning and implementation, along with a lack of land information, is the primary reason why previous attempts at land consolidation in Sub-Saharan Africa's customary lands have failed. They argued that since traditional methods of land management are based on Western historical ideas that do not apply to all regions of the world, particularly customary lands, responsible approaches are required.

Conversely, land management strategies like reforestation, water management systems, and soil conservation methods are frequently included in land consolidation projects in China and Europe. These initiatives have demonstrated strong potential to reduce soil erosion, desertification, and salinization, among other forms of land degradation. As shown in the results of **Study 1**, particularly in China, Central and Eastern European countries, and some Western European countries, land consolidation has a positive effect on land degradation types associated with the water regime.

Zhou and Cao (2020) examined the land consolidation project in Shaanxi Province, China. Their findings indicate that most of Shaanxi's land consolidation projects are high-quality cropland consolidation projects, land reclamation projects, and cropland consolidation projects. Land reclamation projects and cropland consolidation are the main causes of the increased cultivated land. They came to the conclusion that in order to guarantee China's food security, cropland consolidation and superior cropland construction are crucial. Additionally, in light of urbanization, rural settlement consolidation needs to be implemented in remote areas. However, according to Jin et al. (2017) there is still uncertainty regarding the effectiveness of the land consolidation policy in China. Using a time-series analysis, they assessed the effectiveness of China's land consolidation policy in improving agricultural productivity. Contrary to optimistic estimates based on regional statistical analysis and theoretical approaches, their results demonstrated that land consolidation has a low overall effectiveness in increasing agricultural productivity. The findings of **Study 1** showed that land consolidation could lead to increased water and wind erosion, increased runoff, and loss of vegetation cover, especially in hilly areas in China. In some cases, the intensification of agricultural practices after land consolidation has also reduced organic matter, hampering agricultural productivity.

In the context of Europe, Backman (2016) applied cost-benefit analysis to examine and evaluate the growth and effectiveness of farmland consolidation. Based on the Swedish experience, they discovered and outlined the benefits of farmland consolidation for landlords and society. According to their findings, there are several costs for a land consolidation project, such as investigating the size and composition of each landowner's farm, developing the design of the new consolidated properties, valuing each property, mediating and negotiating with all involved landowners, and surveying the new boundaries. Thomas (2006) attempted to organize the European

Land Consolidation Approaches by addressing several critical questions, such as which type of land consolidation is most likely to solve the structural issues facing rural areas in an appropriate and most suitable way based on the cost-benefit ratio? Which kind of land consolidation is most likely to have the most significant effects and outcomes regarding the ratio of costs to benefits? and, is a comprehensive and essential approach required, or is a voluntary land exchange sufficient? To answer these questions, they suggested analyzing the indicators of the land consolidation practice, such as sustainability and governance. They believed that a land consolidation procedure's technical design primarily dictates the overall costs and, consequently, the costs/benefits ratio. In a similar study, Ntihinyurwa and de Vries (2020) considered land fragmentation and consolidation (defragmentation) approaches as land management tools. They identify the situations in which one could select land fragmentation or defragmentation policies by critically analyzing the known causal-effects relationships between different fragmentation forms and defragmentation strategies. In contrast to the majority of previous research, this study implies that farmland fragmentation is not always a problem. The scenarios and their level of problem or benefit are determined by a variety of locally specific external circumstances, such as biophysical, social, economic, political, technical, and agroecological.

These observations align with the results of **Study 1**, which examined the advantages and disadvantages (cost-benefit) of land consolidation. It was revealed that land degradation often occurred following projects that focused solely on redistributing land without incorporating additional measures. However, in cases where land consolidation initiatives integrated elements such as nature conservation, water management, or erosion control, land degradation was reduced in 66% of the analyzed cases. Moreover, these projects demonstrated a beneficial impact on various types of land degradation. This highlights the importance of understanding the dual nature of land consolidation—both as a subject of academic inquiry and as a tool for crafting more effective policies.

Environmental trade-offs of land consolidation

Maintaining or losing biodiversity?

Biodiversity is influenced by land consolidation practices in two ways. First, building materials can potentially directly damage or significantly disturb wildlife habitats. In addition to destroying natural biological communities, excessive use of concrete, cement, and asphalt has a significant negative impact on soil microorganisms' ability to survive. Second, migration routes and game trails have been altered by engineering practices. The local environment is impacted by artificial building materials, and engineering plans ignore the movement of wildlife. Land consolidation projects alter

the original landscape patterns by leveling the land and rerouting roads and ditches. In a short time, engineering techniques can significantly change the original topography (Zhang et al., 2012).

The loss of habitat is one of the significant adverse impacts of land consolidation on biodiversity. In order to create larger and more consistent fields, the land consolidation process frequently entails clearing hedgerows, natural vegetation, and other non-crop habitats. As a result, species that rely on these habitats for survival may become extinct. Consolidation projects would have resulted in the long-term habitat exclusion of threatened species, for example, according to a study conducted in Japan that found plant species tended to be excluded from heavily consolidated areas (Osawa et al., 2016). According to Denac and Kmecl (2021), land consolidation projects in Slovenia have also been linked to the decline of bird and insect populations and the loss of traditional farmland biodiversity. Their results showed that the proportions of various meadow types, hedgerows, solitary trees, succession, and traditional orchards were higher in non-consolidated sites. Non-consolidated sites had higher farmland bird diversity and abundance levels for most farmland bird species.

Dudzińska and Kocur-Bera (2014) stated that space is greatly influenced by land consolidation, which frequently results in dramatic changes to spatial patterns. They believe that the land consolidation process affects the environment in both positive and negative ways in Poland. They examined the environmental safeguards put in place during the land consolidation procedure. According to their research, the benefits of land consolidation projects included reducing soil erosion, enhancing trophic conditions, promoting biological activity in the soil, and raising the amount of organic compounds in the soil. Regarding the adverse effects associated with land consolidation, their findings showed that the engineering practices will eliminate native species and habitats and can considerably alter the original topography in very short periods of time. The intensification of agricultural activities caused by land consolidation is also linked to a decrease in the area of mosaic habitats, the conversion of grasslands into arable land, and the allocation of additional land for farming. Reduced natural and semi-natural habitats, the loss of mid-field trees, ponds, and strip boundaries, the extinction of crop-field-dwelling plant and animal species, the isolation of wildlife enclaves, and increased erosion are all consequences of these processes.

Minimizing or maximizing soil erosion?

Depending on how the land consolidation process is implemented, it can either mitigate or exacerbate soil erosion. This process decreases soil erosion by increasing the structural integrity of landscapes, encouraging conservation practices, and increasing land use efficiency. Zhang et al.'s (2021) findings showed that carrying out land consolidation reduced soil erosion due to the construction of protection forests,

farmland shelterbelts, and different kinds of land engineering. However, the environmental impacts of land consolidation are not always positive, as they are heavily influenced by the project's specific design, implementation, and regional context.

As discussed earlier, farmland consolidation has many benefits for rural development and agricultural efficiency, but there are drawbacks as well, which differ depending on the area, design, and implementation (Dudzińska and Kocur-Bera, 2014). Among others, soil erosion rates may be inadvertently increased by land consolidation projects, especially those that are exclusively focused on expanding agricultural fields for mechanization and efficiency. Changes in land structure and removing natural barriers like hedgerows and vegetative cover frequently expose soil to wind and water erosion in areas where land consolidation prioritizes land redistribution without incorporating environmental safeguards. Land consolidation initiatives that aim to create larger, contiguous plots for mechanized farming, for example, often lead to higher levels of topsoil loss, according to studies from Southeast Asia and Sub-Saharan Africa (Mensah and Gordon, 2020).

Slope gradients present another challenge in hilly areas. Land consolidation projects that enlarge fields in these types of terrains without putting erosion control measures in place frequently result in increased runoff and the formation of gullies. According to Xu et al. (2021) in China's Loess Plateau, land consolidation projects in steeply sloping areas increased erosion rates by more than 30% due to inadequate planning that ignored topographic and hydrological factors. However, they believed that the land consolidation project measures still have considerable room for optimization to reduce soil erosion further.

For example, one efficient way to mitigate soil erosion is through conservation tillage, which minimizes soil disturbance and keeps crop residues on the soil's surface. Conservation tillage can reduce wind and water erosion by up to 50% (Busari et al., 2015; Montgomery, 2007). Therefore, conservation tillage can be incorporated into the design of new fields in land consolidation projects to maintain soil structure and decrease erosion. There are other management approaches, such as agroforestry and windbreaks (Zhang and Ye, 2024), cover crops (Zhong et al., 2020), and integrated watershed management (Bao et al., 2023) to mitigate the adverse effects of land consolidation on soil erosion.

Since the environmental trade-offs of land consolidation projects were not the main focus of **Study 1**, this study proposed that, in order to prevent unforeseen environmental consequences, a better understanding of the long-term development of farmland characteristics after the implementation of land consolidation projects is necessary.

Water efficiency or inefficiency in drought-prone regions?

Water scarcity remains a critical issue for agriculture globally, particularly in regions prone to drought. The exacerbation of climate change has increased the intensity of drought occurrences, amplifying the focus on sustainable water management practices. Land consolidation initiatives, designed to enhance productivity and efficiency by reorganizing fragmented agricultural lands, present opportunities and challenges for managing water resources. Land consolidation can enhance water efficiency when integrated with adaptive farming systems, particularly in arid and semi-arid regions. Conversely, if not executed properly, it may intensify water stress and lead to the depletion of vital resources.

Due to the scattered smallholder plots, which restrict access to irrigation infrastructure and increase water loss, land fragmentation frequently results in inefficient water usage. Therefore, by combining smaller parcels into larger, easier-to-manage units, land consolidation makes it easier to implement modern irrigation systems like drip irrigation, sprinkler systems, and precision farming techniques. These systems ensure a more efficient distribution of water resources across farmed land by lowering water waste. Combining land consolidation with water management strategies generally results in greater control over water resources, reduced soil erosion, and improved farming systems' overall resilience to deal with climate variability and water scarcity (Xie et al., 2021). According to Arslan et al. (2024), land consolidation and irrigation networks are interconnected due to cost, design, service capability, pipe, and other irrigation scheme components. Particularly, parcel shape, rural roads, and fragmentation have a significant influence on irrigation network costs for water management at farm, community, and regional levels. Their results demonstrated that a more effective and economical irrigation network design can be achieved by combining different land holdings into consolidated plots.

However, if water rights are not fully addressed, land consolidation can sometimes lead to unintended negative consequences. For example, due to increased agricultural expansion and intensification resulting from land consolidation efforts, groundwater resources are being overused in many developing regions. Thus, water-intensive crops may be expanded by farmers with newly consolidated land if proper regulation is not in place, along with further depleting limited water supplies.

The idea for developing **Study 2** emerged from thoroughly investigating how land management practices affect water efficiency in drought-prone regions. Reviewing the complexities of managing water resources and consolidating land made it clear that drought events present more complex issues besides water scarcity. The realization that different farming systems (traditional, conventional, and organic) experience varying degrees of vulnerability to drought sparked an interest in

examining these systems based on the global aspect. Existing research on land consolidation highlighted its potential to optimize irrigation and improve drought resilience; however, it also underscored the risks associated with increased agricultural intensification and resource depletion when governance structures fail to regulate water use effectively. This led to a more thorough examination of how farming systems react to drought events, given their dependence on resources, social and economic conditions, and adaptive capabilities.

Socioeconomic implications of land consolidation

Farmers' empowerment

Land consolidation has several potential benefits to empower farmers, such as improving access to resources, resolving structural inefficiencies in land use, and increasing agricultural productivity. One of the main advantages of land consolidation is mitigating land fragmentation, which is a significant obstacle to efficient farming in many areas. For example, in Eastern Europe, land consolidation projects have increased crop yield by employing practical irrigation and machinery (Pašakarnis and Maliene, 2010). When incorporated into a larger local rural development framework, voluntary land consolidation tools can effectively address the structural issues caused by land fragmentation, according to recent experience from Moldova and a number of other Central and Eastern European countries (Hartvigsen et al., 2012).

Furthermore, land consolidation frequently gives farmers better access to credit and financial services and increases productivity. Farmers can obtain loans for equipment, seeds, and fertilizer investments because larger, consolidated land parcels are more likely to meet the collateral requirements of banks and other lending organizations. The original purpose of land consolidation, according to Lemmen et al. (2012), was to enhance agricultural output through parcel enhancement, lower production costs, and improve farm efficiency. As a result, farmland consolidation improves the allocation and relationships between land and other production factors. Combining farmland allows farmers to reduce travel time and operating expenses while maximizing labor and equipment movement. Land consolidation has resulted in positive outcomes for agricultural output in countries like the Netherlands, Germany, and Denmark. Although state ownership and private property rights are prevalent in these countries, there is a lack of scientific research on the application of land consolidation in the context of customary tenure, which involves communal land ownership. For instance, land consolidation has not been used in Ghana, a country where customary tenure predominates, as a means of promoting agricultural development and farmer empowerment (Abubakari et al., 2016).

Farmers' negotiating power in markets can also be strengthened by land consolidation. Farmers can produce more crops by combining their land, which enables them to

bargain with buyers for lower prices and reduce their reliance on intermediaries. For example, land consolidation projects in Vietnam have allowed rice farmers to organize into cooperatives, which have lowered post-harvest losses and negotiated higher prices for their produce. Additionally, by facilitating the exchange of information and resources, these cooperatives have given farmers even more opportunities to enhance their farming methods (Nguyen et al., 2020).

Moreover, land consolidation can support rural development by enhancing public services and infrastructure. Building roads, irrigation systems, and storage facilities are a core element of consolidation projects, which benefit participating farmers and the larger community. According to a study by Janus and Ertunç (2021), land consolidation projects provided access to an irrigation network, which is one of the main objectives of the projects in Turkey's water scarcity conditions. Their results also showed that plot shape improvement is evident in projects carried out in Turkey. Plot boundaries have been shortened, which has improved farm operating conditions to some extent because some cultivation operations have become much less efficient along the boundaries.

Smallholder farmers' marginalization

Despite the potential benefits of land consolidation, it may also exacerbate inequality and eliminate smallholder farmers, especially in areas with inadequate or unfair land tenure systems. Smallholder farmers, who usually lack official land titles or access to capital, are typically excluded from the benefits of land consolidation, and the process may even result in their displacement. Land consolidation projects prioritizing the interests of more prominent landowners or agribusinesses often leave smallholder farmers vulnerable to land grabbing and dispossession.

One of the main issues facing smallholder farmers is the lack of legal recognition of their land rights. In many developing countries, smallholder farmers find it difficult to provide proof of their land ownership because of informal or insecure land tenure systems. As a result, they are usually excluded from land consolidation initiatives or obligated to sell their property for less than its market value. In Sub-Saharan Africa, for example, land consolidation projects have often resulted in the concentration of land ownership among wealthy elites, excluding smallholder farmers from their land, leaving them in poverty. In regions where land is the main source of income, smallholder farmers who lose access to their land usually face severe financial hardship, making this marginalization particularly severe (Asiama et al., 2021).

Smallholder farmers might lack the resources and influence to fully engage in land consolidation initiatives, even when they are involved in decision-making processes. Furthermore, smallholder farmers often have limited credit to cover the costs associated with land consolidation, including surveying and legal fees, which are

extremely expensive. Moreover, smallholder farmers may lack the technical knowledge and social networks required to manage every step associated with land consolidation. In India, for instance, smallholder farmers have complained about feeling excluded from decision-making procedures usually dominated by larger landowners and government representatives. The consequences of this exclusion may favor wealthier farmers disproportionately, exacerbating socioeconomic inequality (Malabayabas and Mishra, 2022).

Another significant issue is the displacing of smallholder farmers due to land consolidation. Consolidation projects often re-distribute land to create larger, more efficient units, which could result in the eviction of smallholder farmers. This is particularly common in regions where the primary forces behind land consolidation are the expansion of commercial agriculture or the construction of infrastructure. For example, land consolidation projects to establish large-scale agricultural production in Sub-Saharan Africa have driven many smallholder farmers to move to urban areas for work. Thus, this displacement compromises the livelihoods of farmers and disturbs rural communities and social networks (Asiama et al., 2021).

Overall, the need for careful planning and execution is highlighted by the dual effects of land consolidation, which empower some farmers while marginalizing others. To guarantee that land consolidation benefits all farmers, policymakers must prioritize inclusive and context-based strategies that consider the unique requirements and difficulties faced by smallholder farmers. This requires strengthening land tenure structures, offering smallholder farmers financial and technical assistance, and ensuring their opinions are noticed during decision-making.

The initial spark of **Study 3** was ignited by the analysis of the broader implications of land consolidation, specifically how it affects farmers and land tenure security. It was evident that secure land tenure is essential for protecting farmers from land grabbing and displacement while examining how land consolidation projects may exacerbate inequality by giving preference to agribusinesses and large landowners. As a result, many farmers, particularly in regions with weak legal frameworks, risk losing their land when consolidation efforts prioritize commercial interests over equitable land distribution. Specifically, insecure land tenure accelerates agricultural land to urban use (ALCU) and marginalizes smallholder farmers. Overall, farmers without official ownership are more likely to sell their property, which leads to fragmentation of agricultural landscapes and rapid urbanization. Here is the main question: What is the global impact of various land tenure security models on ALCU? Although previous research had investigated this relationship at the national level, meta-analysis studies that combined findings from several countries were lacking.

Dimensions of drought across different farming systems

Traditional farming system and its potential

Drought is a major global natural disaster affecting different farming systems and human society today. Agriculture is the primary source of income in rural communities in arid and semi-arid regions of the world, where drought is one of the most damaging natural hazards. Consequently, farmers are the most immediate victims of drought, as diminished crop yields result in substantial economic losses that have devastating effects on the livelihood security of rural families. In response to drought events, conventional, organic, and traditional farming systems all show unique vulnerabilities and adaptive capabilities.

Due to their deep roots in historical agricultural methods, traditional farming systems have evolved adaptive mechanisms that minimize the effects of drought. These systems are inherently resilient to climatic variability because of their low reliance on external inputs, varied cropping patterns, and reliance on indigenous knowledge. Although the majority of traditional agricultural practices are location-specific, developing over time within a specific habitat and culture, many of them have agroecological characteristics in common (such as a high number of plant and animal species, high structural diversity, exploitation of a wide variety of microclimates, reliance on local resources and crop varieties, etc.) that scientists have identified to improve the stability and resilience of farming systems (Altieri and Nicholls, 2017).

Given the present and predicted drought events, agroecology has become one of the most reliable pathways to sustainable and equitable development. These agroecological systems, well-established examples of productive agricultural systems, are rooted in the ecological rationale of traditional small-scale farming. According to research by Altieri and Nicholls (2017) farms that used crop rotation and intercropping experienced less yield loss during drought than those that used monoculture systems. Furthermore, conservation methods like mulching, terracing, and rainwater harvesting increase water efficiency and lessen soil erosion. According to the thorough literature review, **Study 2** also discovered that farmers who engage in traditional agriculture employ a variety of strategies to deal with drought, including intercropping, field rotation, seasonal calendaring, no-tillage farming, adjusting planting times, before-drought seeding, etc.

Farmers in arid and semiarid regions have created management techniques over many generations to increase the soil's ability to retain water for plant use, reduce its vulnerability to drought, and aid in preventing soil erosion and degradation. For example, ridges are inserted regularly across the furrows between crops planted on raised beds in water-limited areas, such as Nigeria. Known as "tied ridges," these formations aid in retaining rainfall, reducing runoff, and promoting water infiltration. (Barrow, 1999). Farmers in Tigray, Ethiopia, create contour furrows at 2–4 meters

intervals for *teff* cultivation, known locally as *terwah*, to capture water in the ridges. This practice results in fields resembling a mixture with elongated pools of retained water after a storm, facilitating later crop utilization rather than allowing runoff loss (Boers and Ben-Asher, 1982). In reference to traditional strategies for dealing with drought occurrences, **Study 2** proposed a traditional water harvesting system called Ab-bandana, which consists of artificial "water reservoirs" or "artificial wetlands" in Iran's Mazandaran province that range in size from 3 to 1000 hectares (Mirzaei et al., 2019).

However, traditional farming faces challenges such as land tenure insecurity, limited access to modern technologies, and high labor intensity. Policies that promote secure land rights, knowledge transfer, and infrastructure development are critical to realizing the full potential of traditional farming systems in drought-prone areas.

Organic farming system and its paradox

Organic farming is frequently marketed as a sustainable method that improves biodiversity, soil health, and water conservation. However, there is a paradox in how it responds to drought. Although organic systems typically enhance soil structure and water retention, they may also have restricted irrigation options and lower yields during severe drought conditions. Researchers (Röös et al., 2018; Seufert et al., 2017) have shown that adding organic matter increases the biological diversity below ground, making conditions favorable for plant roots and enabling the growth of robust, resilient, and healthy crops. Therefore, soil organic matter (SOM) is the key strength of organic farming in drought resilience. SOM increases the soil's ability to retain water, which helps crops withstand drought. It also increases infiltration, reducing runoff and preventing soil particles from being carried with water during heavy rains. Reganold and Wachter (2016) stated that organic farms exhibited better moisture retention and reduced runoff, leading to greater drought tolerance than conventional farms.

By highlighting organic farming as a sustainable livelihood strategy with decades of experience in multiple climate zones and a wide range of unique local conditions, **Study 2** suggests that adaptation strategies can be built on well-established practices. Drought conservation tillage, eliminating synthetic inputs, soil moisture monitoring, and mulching are the primary adaptation techniques in this kind of farming.

However, under severe drought conditions, organic farming also has serious drawbacks. Reliance on manure and compost-based nutrients instead of synthetic fertilizers can slow plant growth, increasing the vulnerability of crops to water stress. Furthermore, organic farms are vulnerable in arid and semi-arid regions because they frequently rely on natural precipitation rather than intensive irrigation. After eight years of contrasting management, Wittwer et al. (2023), found that prolonged drought

had significant negative effects on all crops examined and for all four cropping systems (conventional and organic with and without soil conservation tillage). Surprisingly, they discovered that conservation tillage and organic management had only a limited adaptive capacity to mitigate the effects of drought.

The economic viability of organic farming during drought events is another challenge. The profitability of organic farming during droughts presents another difficulty. Prolonged water scarcity can make farmers' financial problems more serious because organic yields are usually lower than conventional yields. Furthermore, drought-stressed environments make it more difficult to manage weeds and pests without chemical input, which reduces productivity. Therefore, consumers' willingness to pay a premium price is crucial to the profitability of organic farming. According to Crowder and Reganold (2015), the actual premium is about 30%, but a 5–7% premium is needed for organic farming profits to match those of conventional farming.

To enhance the drought resilience of organic farming, it is recommended to incorporate drought-resistant crop varieties, improve water management through rainwater harvesting, and implement agroforestry practices. As suggested by **Study 2**, combining traditional practices with ecological science can improve the adaptive capacity of organic agriculture to tackle the impacts of drought events.

Conventional farming system and its hidden resilience

High-yield crop varieties, intensive mechanization, and synthetic inputs are the main features of conventional farming, known as resource-intensive and environmentally unsustainable. However, its ability to cope with drought conditions demonstrates hidden resilience because of precision agriculture and technological advancements.

The availability of high-efficiency irrigation systems, like drip and pivot irrigation, is one of the main benefits of conventional farming regarding drought adaptation strategies. According to studies (Ponisio et al., 2015; Wittwer et al., 2023), modern irrigation methods can maintain crop yields while reducing water usage. Additional strategies include the planting of high-yielding plant varieties and crop insurance, which enhance income security and offer financial support in the event of crop failure due to drought (Ben-Amar et al., 2020). As stated in **Study 2**, a key component of water (and food) security, especially in regions with conflicting interests in water resources, is integrated water resources management, which farmers employ in conventional farming. Thus, water consumption is reduced, and efficiency is increased by using an effective irrigation technique.

Precision agriculture enhances drought resilience by optimizing water application using data-driven irrigation scheduling, remote sensing, and soil moisture monitoring. Specifically, during prolonged drought events, these innovations guarantee that crops

receive enough hydration and minimize water waste. For example, satellite-guided irrigation systems have been successfully installed on large-scale farms in the United States, resulting in noticeable increases in productivity and water efficiency (Lobell et al., 2011). However, conventional farming can compromise long-term drought resilience, even using these technological advantages. Over time, the overuse of synthetic pesticides and fertilizers deteriorates soil health and reduces the soil's natural ability to retain water. Additionally, the extensive groundwater extraction for irrigation has caused aquifer depletion in a number of agricultural areas leading to severe water scarcity. According to Birkhofer et al. (2021), conventional farming is practical for dealing with short-term drought stress, but soil ecosystem functions as fundamental components of ecological intensification approaches may be threatened under long-term conventional farming.

Overall, conventional farming systems should use conservation agriculture techniques like cover crops, reduced tillage, and soil organic matter enhancement to balance sustainability and productivity. Furthermore, regulatory frameworks must be implemented to prevent excessive water resource extraction while promoting appropriate irrigation techniques.

The extent of drought impacts and possible adaptation solutions

Traditional, organic, and conventional practices

Traditional farming systems often rely on indigenous knowledge and locally adapted practices that have evolved over centuries to cope with water scarcity. It is worth mentioning that in traditional farming, drought events result in a loss of agricultural products, livestock and human malnutrition, land loss, economic stagnation, an increase in disease, and community migration, all of which endanger livelihoods on a regional and national scale. As stated in **Study 2**, due to the severe drought, traditional farming productivity in India's arid regions has dropped by 40%. As a result, farmers stopped working in these fields, which were their main source of income (Srivastava et al., 2016). Similar to this, southern Africa's extreme drought has led to less water for irrigation and cattle as well as less grazing for livestock, which has a detrimental effect on agricultural livelihoods and caused shortages of food in traditional farming (Mensah and Gordon, 2020).

Overall, according to **Study 2**'s findings, 22.7% of the primary articles discussed adaptation strategies in conventional farming systems. Agroforestry, field rotation, intercropping, agricultural composting, and combined crop-animal protection cultivation were the primary traditional agricultural techniques discussed in the collected articles. Regarding the collected studies' implementation date, the results positively influenced traditional farming systems. Extending the data collection period by a year has a more significant economic (52%) impact on traditional

agriculture. As per the geographical distribution of the collected studies, the effects of droughts on economic impacts in traditional farming systems were significant in America, Asia, and Europe by 2.11, -2.89, and -1.33, respectively. This indicates that droughts that occur in traditional agricultural systems have a negative impact on the economies of Asia and Europe. Droughts in American countries have significantly affected livelihoods in traditional farming systems by -1.02. Droughts in Asian countries have also significantly negatively impacted the environment in traditional farming systems (-0.99).

In arid and semi-arid regions, crop diversification, agroforestry, and climate-smart agricultural practices seem successful. Crops that require a lot of water, like rice, could be replaced by crops that require less, like maize. Future agricultural research should concentrate on creating drought-resistant rice varieties as part of adaptation strategies, even if farmers decide to plant the crop (Ghimire et al., 2010). Other significant adaptation strategies that farmers employ include agroforestry integration, mixed cropping promotion, crop variety changes, crop timing changes, increased use of farmland manure, organic farming, replacing failed crops, biopesticide use, fallow field, conservation agriculture promotion, and crop-livestock integration (Biggs et al., 2013).

Climate-smart agriculture practices have adopted crop diversification and agroforestry techniques to maintain soil and water resources, support livelihoods, and guarantee food security. Finally, this opens up new opportunities for improving crop diversity, productivity, revenue streams, and the environment. The traditional crop varieties and cropping patterns, which are highly valued by local society and individual families, are in danger of disappearing. Despite the low returns from traditional crops because of drought, it may even lead to resistance, particularly from older farmers, who may decide to switch to a new farming method. Similarly, conservation agriculture might support crop productivity and moisture retention. Furthermore, Other structural adaptation strategies that mitigate the impact of drought in farming systems include installing an early warning system for drought events, rainwater harvesting, irrigation channels, conservation ponds, and affordable soil conservation technologies (Baudron et al., 2014). Regarding different farming systems, it should be considered that each farming system (i.e., traditional, organic, and conventional) adopts unique adaptation strategies to cope with drought and climate variability.

Based on the **Study's 2** findings, adaptation strategies increased traditional farming systems' average economic, livelihood, and environmental impacts by 0.14%, 0.86%, and 0.62%, respectively. According to the collected studies, the best adaptation strategies practiced in traditional farming are on-farm biodiversity, soil management, and water harvesting. As a result, protecting traditional management systems and implementing agroecology-based management strategies may be the only effective

way to increase the productivity, sustainability, and adaptability of traditional farming under the predicted climate scenarios.

Organic agriculture promotes soil health and biodiversity, which helps build drought resilience. Because organic farming is more productive than conventional farming, crop production losses due to drought may be lower; therefore, most organic farming systems use less water. However, organic farms often face challenges due to limited access to irrigation and lower productivity during extreme droughts (which was not significant in the findings of **Study 2**).

According to **Study 2**, approximately 31.9% of the primary articles analyzed adaptation strategies in organic farming systems. One of the primary methods employed was an environmentally friendly production process that eliminated synthetic inputs like fertilizers, pesticides, and herbicides. The findings had a favorable impact on organic farming systems when taking into account the implementation dates of the collected studies. Therefore, there is a 21% greater environmental impact on organic farming systems when the data collection period is extended by one year. The geographical distribution of the collected studies indicates that, at about 3.83%, the impact of droughts on the financial aspects of organic farming systems in Oceania is substantially less than that of other regions.

Based on the **Study's 2** review, organic farmers face less financial loss if an entire crop fails because they have spent less on inputs. Moreover, organic farming systems often have higher concentrations of soil organic carbon (Büchi et al., 2022) and plant symbionts are more abundant in organic farming systems (Banerjee et al., 2019), These factors may help improve soil aggregation and water retention (Pimentel et al., 2005) which in turn may increase drought resistance.

Other studies (Ardón et al., 2016; Lebreton et al., 2016; Schwantes et al., 2016; von Schiller et al., 2015) investigated how severe drought affected ecosystems and dissolved organic matter. These results suggest that crop diversity and enhanced water-holding capacity on organic farms would lead to drought tolerance and other financial advantages. Thus, in a single production system, diversity guards against adverse price changes. Another benefit of diversified farming is that inputs are distributed more seasonally. Diversified farming also has the advantage of more seasonal input distribution. Organic crop management strategies can also be beneficial in coping with climate change, as they include soil and crop characteristics that can reduce the ecosystem's vulnerability to extremes. Therefore, the **Study's 2** findings suggest that organic farming could act as a drought buffer, even if drought conditions have a direct and negative impact on soil characteristics.

Globally, intensive farming, which requires a lot of input, was chosen as a solution to the world's problems. However, there are adverse ecological and environmental side effects from the way the land is used. Given that the sustainability of the agricultural sector is crucial for the economic growth and development of countries worldwide,

the primary question that emerges at the microeconomic level is whether a farm should switch from conventional to organic farming.

Conventional farming has the potential to be resilient to drought impacts through technological advancements like precision farming and high-efficiency irrigation, which can have about 7% economic impact, as stated in **Study 2**. However, because of its dependence on external sources and energy-intensive processes, this farming system is vulnerable to supply chain interruptions and rising production costs during water scarcity. According to **Study 2**, one of the reasons that this farming system is vulnerable is that smallholder farmers have inadequate facilities and supplies. Under these circumstances, if rural farmers' livelihoods become unstable, they will be forced to abandon agriculture. The extensive use of environmentally harmful chemical products, like pesticides and fertilizers, is another drawback of conventional farming. According to **Study 2**, the negative consequences of traditional systems include a considerable loss of soil organic matter and physical and biological deterioration of the soil, which eventually lessens the soil's capacity to withstand extreme events like drought. Therefore, organic farming should be more beneficial in terms of the environment, society, and economy, as well as health and food safety. Increasing the cultivated areas allocated to organic farming will result in more profitable productivity in terms of maintaining soil health, but Cristache et al. (2018) found a positive relationship between gross fixed capital formation and the annual change in conventional agriculture production.

Regarding adaptation strategies facing drought events, the findings of **Study 2** showed that conventional farming systems had a frequency of 45.4% in the primary articles. High-yielding plant varieties, automation, and natural chemical additives were among the most common methods. For example, in Germany, focusing on the conventional farming system, Macholdt and Honermeier (2017) investigated he significance of farmer diversity selection in cereal production and the identification of drought-tolerant crop species. Their results suggest that more attention should be paid to adopting varieties that are environmentally friendly and have high yield levels, as this will probably increase overall cereal yield and lower the risks of drought-related crop production.

The role of policy and governance in different farming systems

Land use, resource allocation, financial incentives, and the overall sustainability of farming systems are all influenced by policies, but the governance mechanisms governing conventional, organic, and traditional farming systems differ greatly, reflecting their distinct challenges and characteristics. Effective governance and policy frameworks are crucial for influencing agricultural practices, especially drought resilience and climate adaptation.

Local governance structures are crucial in traditional farming systems, frequently based on indigenous knowledge and communal land management. Policies that promote resource-sharing arrangements, secure land tenure, and sustainable water management are essential to these systems. Community-led projects have effectively increased traditional farming's resilience to climate shocks in many developing countries. For example, communities in Sub-Saharan Africa have been able to use water-saving strategies like terracing and *zai pits* because of decentralized governance and traditional land tenure systems (Kimaru-Muchai et al., 2021). However, in certain areas, farmers' access to government aid and credit is restricted due to the absence of formal land ownership rights, which decreases their capacity to fund adaptation measures (Abubakar et al., 2024). Conversely, in South America, the governments have promoted an agroecological paradigm, recognizing their role in biodiversity conservation and climate resilience. Latin American policies have the potential to significantly improve the region's small farmers, rural communities, and urban populations on an environmental, economic, and political level (Altieri and Toledo, 2011). However, the challenge is weak enforcement and competing land-use policies, like mining concessions, which frequently undermine these initiatives (Aguilar-Pesantes et al., 2021).

Regulatory frameworks that specify certification requirements, input limitations, and market incentives have a significant impact on organic farming. There are still obstacles in scaling up organic production and ensuring fair benefits for farmers. However, many governments have implemented policies to support organic farming as an environmentally friendly replacement for conventional farming. The Common Agricultural Policy (CAP) of the European Union (EU) has funded research and offered subsidies to encourage the expansion of organic farming. It is the goal of the EU's Farm to Fork Strategy to increase organic farmland to 25% of all agricultural land by 2030 (European Commission, 2021). As stated by Guthman (2004), the USDA Organic Program's organic certification in the US guarantees compliance with environmental and health regulations. However, critics argue that federal subsidies unfairly benefit large-scale organic farms, limiting smallholder farmers' ability to transform. Similarly, in India, some policies support organic farmers through training programs and market access facilitation. However, in areas prone to drought, organic farmers face significant challenges, such as inadequate irrigation infrastructure (Tripathi et al., 2023).

The most heavily regulated farming system is conventional agriculture, where laws affect everything from environmental restrictions to input subsidies. Even though industrialized farming has benefited from technological advancements and economies of scale, its dependence on chemical fertilizers, mechanization, and intensive irrigation poses serious governance issues, especially considering water use and environmental impact. For example, Chinese government policies have supported precision agriculture and highly effective irrigation systems to reduce water waste in

conventional farming. Although programs like the "Sponge City Initiative" seek to increase water conservation, groundwater depletion is still a significant problem, especially in areas that produce rice and wheat (Qiao et al., 2020). Establishing water trading markets in Australia has improved agricultural water use efficiency by enabling farmers to purchase and sell water rights. This system has been criticized for aggravating inequality by giving preference to wealthier agribusinesses despite the fact that it helped large commercial farms adapt to drought conditions (Wheeler et al., 2014). As a different example, the Farm Bill provides significant federal subsidies to conventional farming in the United States, especially for crops like corn, soybeans, and wheat. These subsidies improve food security but encourage monoculture farming, lowering biodiversity and making people more susceptible to climate shocks (Sumner, 2003).

Overall, sustainable agriculture will require integrated policies that combine technological innovations with traditional knowledge, equitable resource distribution, and climate adaptation measures in a world increasingly affected by drought and water scarcity. Additionally, as mentioned in **Study 2**, governments can support organic farming and organic techniques through agricultural research and extension systems to help farmers adapt to the effects of drought and climate change. Therefore, integrating ecological science with traditional methods can improve organic farmers' ability to adapt to the effects of drought.

Land tenure security: A key to farmland preservation

As discussed earlier, there are many obstacles to sustainable farmland management in developing countries, such as unpredictable weather, frequent pest and disease invasions, numerous market failures, restricted access to advanced technologies, the absence of formal land ownership rights, and rapid urbanization. Furthermore, due to the transfer of rural laborers and the degradation of farmland, the pressure on the sustainable use of farmland is increasing. Farmers in such conditions are more likely to experience crop failure and low yield because of their limited ability to adapt to these limitations, leading them to convert their farmland to urban use.

Land tenure security plays a critical role in ensuring the sustainability of agricultural land, particularly in the face of growing urban expansion and in mitigating risks associated with agricultural production. For example, i) to increase yield and mitigate production risk, farmers are encouraged to implement agricultural technologies and make long-term investments by having secure land rights (assurance effect) (Bambio and Bouayad Agha, 2018), ii) to raise expected yield and minimize yield variability, land that has been tenured but is inefficient can be sold for cash, which helps improve investment on lands (realisable effect) (Feder, 1987), and iii) to finance investments

in risk-coping management techniques, secure land tenure has a higher collateral value (collateralisation effect) (Carrer et al., 2020).

The new wave of incentive-based policy tools that seek to promote farmland investment and increase the effectiveness of farmland use must address the issue of agricultural land tenure security. Additionally, several qualitative and quantitative studies have demonstrated that insecure farmland property rights are the primary cause of insufficient farmland investment in developing countries (Cao et al., 2020; Gao et al., 2017). Therefore, higher land tenure security can encourage farmers to invest more in agricultural production factors (e.g., fertilizers, organic manure, and agricultural machinery) (Gao et al., 2017), particularly ongoing investments (e.g., maintaining irrigation canals, conserving soil, and planting green manure) (Akram et al., 2019), which will boost agricultural productivity and income and promote farmland preservation (Deininger and Jin, 2006). However, farmland is still under pressure from economic incentives, policy gaps, and rapid urbanization, resulting in irreversible land use changes. Thus, designing policies that balance development and farmland preservation require an understanding of how various tenure systems affect agricultural land conversion.

What are the drivers of agricultural land conversion?

Conversion of agricultural land is a phenomenon that is nearly inevitable during times of economic expansion and population expansion. The question of whether agricultural land should be preserved or put to other uses is up for debate. To put it another way, there is intense competition for land use, usually between the agricultural and non-agricultural sectors, due to the finite and non-renewable nature of the land supply. As a result, agricultural land is converted, drastically lowering the amount of available agricultural land and threatening food security. Ironically, developing countries have the highest rate of agricultural land conversion, owing to their large populations and high food consumption.

Conversion of agricultural land is the outcome of a continuous, complex interaction between socioeconomic, policy, and environmental factors. Furthermore, socioeconomic factors interact in various context-based ways to drive agricultural land conversion under various policy dimensions. One important effect of socioeconomic factors influencing agricultural land conversion is that it could lead to more farmers leaving the area, either permanently or temporarily, in search of better economic opportunities in other areas (Azadi et al., 2016).

Many processes shape landscape patterns and determine their spatial organization, all influenced by biophysical and socioeconomic factors. A few researchers, including Setiawan and Purwanto (in Firman, 1997), classified these drivers into two categories: internal and external. Government policy, road infrastructure development,

industrialization (Lichtenberg and Ding, 2008), and urbanization (Ho and Lin, 2004a) are the main external drivers. The two main internal drivers are technological intensity and land productivity (Levia and Page, 2000). Ho and Lin's (2004a) that China's coastal cities experience farmland conversion as a result of industrialization. Their research revealed that China's industrialization process frequently coincides with urbanization, which leads to the conversion of farmland. A growing population necessitates the expansion of built areas to accommodate more housing and job opportunities, which in turn affects the conversion of agricultural land. In numerous developing countries like Indonesia, China, Vietnam, and the Philippines, the majority of economic development policies indirectly encourage intensive land conversion while also promoting industrial growth (Ho and Lin, 2004b; Michler and Shively, 2015; Nguyen et al., 2016; Xu et al., 2015). Levia and Page (2000) examined the driving forces of agricultural land conversion to residential uses. The variables that are thought to be contributing to farmland conversion in Massachusetts are farm size, farm slope, and distance from the closest cities and highways. They discovered that the main factors influencing the conversion of agricultural land are all of those variables. The need for labor will decline as agriculture adopts more advanced and modern technologies. The agricultural industry will experience a labor surplus due to technology. These workers will seek employment in cities, necessitating more land for more services to support the expanding population and economy. Thus, the likelihood of agricultural land conversion increases as cities spread into outskirts areas (Tan et al., 2009).

Overall, the impact of shifting land use from agriculture to urbanization has been extensively studied, but the majority of the existing literature consists of case studies with varying definitions and approaches that focus on individual countries or regions. Despite their usefulness, these studies have limited generalizability regarding the global factors influencing land conversion to urban use (ALCU), and it is possible to conclude that the relationship between ALCU and land tenure security has not yet been investigated. Therefore, the motivation for **Study 3** was to better understand the impacts of land tenure security variables on ALCU at the global level.

What is the link between land tenure and agricultural land conversion?

Although land tenure security and agricultural productivity have historically been two distinct fields of study, land tenure and titles would have played a significant role in early agricultural economies. Moreover, secure land tenure mitigates the possibility that farmland might be sold or used for urban development by giving farmers the confidence to invest in sustainable land management approaches (Bugri, 2008; Chand and Yala, 2009). Thus, the relationship between agricultural productivity and land tenure security is a relatively recent topic (Atwood, 1990; Chigbu et al., 2019).

Focusing on initial studies, Hanstad (1997) asserted that individual and secure land tenure rights are necessary for a productive agricultural sector, which is crucial for lowering poverty and fostering economic growth. Although the relationships between tenure security and agricultural productivity are of primary interest, Holden and Ghebru (2009) discovered that the opposite relationship may also be significant. They claim that since tenure security is endogenous, there may be a positive relationship between investment and land tenure security, since people invest to increase their tenure security. Regarding the positive impact of land tenure security, several studies have investigated the effect of legal ownership on farm output or income. For example, according to Foster and Sáenz (1970), security of ownership, and income per unit of land had a positive correlation of 0.53 for one province in Costa Rica. Similarly, land certification has increased agricultural investment and enhanced tenure security in Benin. The study found that enhancing tenure security can contribute to investment decisions, particularly during the early formalization phases. Therefore, it was concluded that "households shift their investment decisions from subsistence crops to long-term and perennial cash crops due to improved tenure security from program demarcation activities".

These findings underscore the need for robust socioeconomic analysis of land tenure security variables in **Study 3** to enhance the long-term viability of agricultural land. More recent studies examine the advantages of land registration initiatives over an extended period of time in an effort to show how agricultural productivity and land tenure security are related. However, recent research has not provided a conceptual or empirical description of the relationship between land tenure security and agricultural land conversion. Therefore, the link itself is still open for debate.

Secure tenure slows agricultural land conversion

The ownership puzzle: Private vs. communal

One of the main factors influencing land-use patterns is the security of land tenure, especially when determining how much agricultural land is turned into urban use. Secure tenure mitigates the chance of farmland conversion by influencing farmer behavior, investment choices, and long-term land management plans. Conversely, insecure tenure speeds up urban growth by making agricultural land more susceptible to speculative sales, informal settlements, and government expropriation. In this sense, **Study 3** examined the relationship between ALCU and various facets of land tenure security, such as ownership status, legal recognition, and land-use designations.

The fate of agricultural land is significantly influenced by ownership status. According to studies (Lipski, 2015; Nguyen et al., 2016), privately owned farmland is less likely to become urbanized than state or communally owned land. Private landowners have stronger incentives to maintain agricultural production, make long-

term investments in land improvement, and avoid selling their land for short-term gains. Conversely, state-owned and communal land frequently lacks distinct individual rights, making it more susceptible to unauthorized urban growth and land grabs. As confirmed by the results of **Study 3**, ALCU has decreased by 1.86% on private land. The rationale is that because private agricultural land is typically owned and managed by individuals or organizations with the power to decide how it will be used and developed, it is less susceptible to conversion to urban areas.

In contrast, for communal land, **Study 3** showed a mean effect of 1.92, demonstrating that land tenure security did not have a significant effect on ALCU. The rationale is that due to the immediate financial advantages of urban development projects, the community may be more inclined to approve them when there is no exclusive ownership. Additionally, the lack of formalized legal protections in communal land tenure frequently facilitates the appropriation of land for urbanization by external parties like governments or private developers. In many areas, communal land is not formally recorded in cadastral systems, making it susceptible to reclassification for non-agricultural uses or expropriation under eminent domain laws (Wily, 2011). As indicated by Gottlieb and Grobovšek (2019), the main effect of communal land tenure is to keep farmers disproportionately unskilled, which contributes to the explanation of the agricultural productivity gap in the world's poorest countries.

The power of land titles

The security, stability, and economic value of land are all significantly influenced by land titles, especially in the agricultural context. Land use decisions are greatly influenced by a titled piece of land, which provides the owner with formal recognition and legal protection, guaranteeing long-term tenure security, including ALCU. Conversely, untitled land is more vulnerable to urban growth and degradation since it is frequently the subject of disputes, expropriation, and ineffective land management.

More substantial property rights are linked to titled land, providing farmers with the legal guarantee that their land will not be taken or reallocated without justification. This security eliminates the possibility of turning agricultural land into urban areas by encouraging long-term investments in irrigation, soil conservation, and sustainable farming practices (Wannasai and Shrestha, 2008). Other studies (Mutangadura, 2007; Tatsvarei et al., 2018) showed that farming on titled land has led to more sustainable land use than farming on untitled land. The synthesized results of **Study 3** also demonstrated that ALCU occurs significantly less on titled land with a mean effect of -2.97. This finding is consistent with a meta-analysis by Lawry et al. (2017), which found that land titling programs in Latin America and Africa led to a significant increase in agricultural investments, strengthening tenure security and discouraging urban growth. Focusing on agricultural productivity, Charoenratana and Shinohara (2018) and Kubitza et al. (2018) showed that plots, where farmers have formal land

titles, are cultivated more intensively and have higher productivity than plots without titles. In contrast, **Study 3** found that untitled land has a high ALCU, with a mean effect of 7.96. This suggests that lacking formal legal titles leads to speculative land grabbing and government expropriation, accelerating ALCU (Tatsvarei et al., 2018).

By investing in productivity-boosting technologies, landowners can increase agricultural resilience and reduce the pressure to sell land for urban development owing to this financial leverage. On the other hand, untitled landowners frequently have trouble obtaining loans, which makes it harder for them to continue running profitable farms and makes selling land for non-agricultural uses appealing.

A look at tenant vs. owner farming

Reforming land rights in developing countries is widely supported by the idea that farmlands held under secured land rights are more productive than those held under other agreements. For example, due to the assurance that farmers will remain on the land long enough to benefit from the rewards of their investment, a secure tenancy arrangement encourages them to make investments that will improve soil quality and productivity (Sklenicka et al., 2015). Additionally, tenant farmers frequently face financial and legal restrictions that can accelerate the conversion of agricultural land into non-agricultural uses, while owner-farmers generally exhibit better land stewardship (Ali et al., 2012). Therefore, determining ALCU requires understanding the distinction between owner-farmed and tenant-farmed land.

Investment incentives are one of the main distinctions between land farmed by owners and land farmed by tenants. Because they have a stake in sustaining land productivity over time, owner-farmers are more likely to implement long-term conservation techniques like crop rotation, soil enhancement, and irrigation improvements. Despite the extensive empirical literature on the effects of land tenure security on investments and efficiency, the evidence remains mixed (Ali et al., 2012; Deininger et al., 2011). For example, on one hand, Banerjee and Ghatak (2004) showed that land farmed by owners leads to better crop shares, contributing to positive impacts on investment and productivity and less ALCU. On the other hand, a study on Tunisia by Arcand et al. (2007) found no statistically significant difference in ALCU or productivity between land farmed by owners and land farmed by tenants in Tunisia. However, most of the studies show that ownership increases the likelihood of farmers adopting sustainable agricultural practices and less incentive for converting agricultural land to urban use (Jiang et al., 2013; Place, 2009). It was also confirmed by **Study 3** that ALCU takes place significantly less on land farmed by its owner, with a mean effect of -3.42. The rationale is that the farmers who own their land are more likely to resist urban expansion, as they have a stronger attachment to their land and its agricultural value.

Conversely, the majority of tenant farmers are obligated to operate under short-term lease agreements, which tend to discourage them from making substantial land improvements on land and are more prone to urban expansion. As suggested by Lawry et al. (2017), leased farmland is less likely than owner-managed farms to implement soil conservation measures. Tenants frequently prioritize maximizing short-term yields over guaranteeing long-term sustainability because they do not have long-term access to land. It was also indicated in **Study 3** that renting farmland can lead to less sustainable decisions, and they recommend land reallocation (Potthoff and Dramstad, 2023). The statistical findings by **Study 3** also show that ALCU takes place with a mean effect of 2.64 in land farmed by tenants.

The role of designated agricultural land

The designation of agricultural land is essential for preserving farmland and reducing the pressures associated with urban expansion. According to the literature, farmland loss is lower in areas with strong agricultural zoning regulations than in non-designated areas. In the United States, for instance, agricultural preservation initiatives have been effective in minimizing urban expansion in states such as California and Maryland (Daniels and Lapping, 2005; van Vliet et al., 2016). One of the main factors contributing to this success is the administrative and legal framework that limits land-use change. For instance, China's Basic Farmland Protection System, which prevents the conversion of designated agricultural land without official approval, has reduced the loss of farmland considerably over the previous 20 years (Wang et al., 2023). As shown by **Study 3**, the mean ALCU decreased by 2.62% when the land was formally designated for agriculture due to market dynamics, regulatory protections, land use policies, and community engagement aimed at preserving agricultural resources and landscapes.

However, there are some challenges linked to designated agricultural land. For example, poor zoning enforcement in many areas enables urban developers to get around restrictions, frequently through corruption or unofficial talks with local officials. Furthermore, when political and economic priorities change, land designated for agriculture could sometimes be redistributed. Long-term farmland preservation goals have been undermined in rapidly urbanizing countries like India and Africa, where farmland initially intended for agricultural use has been rezoned to accommodate housing demands and infrastructure projects (Lall et al., 2017; Paltasingh et al., 2022).

Due to its lack of legal protection from urbanization, non-designated agricultural land is far more vulnerable to conversion. According to studies (Angel et al., 2010), farmland is more likely to be fragmented and sold for commercial development in areas without formal recognition of agricultural land. Therefore, improving farmers' access to land, better recognition of customary land rights, and more effective

protection of land without recognized claims could be helpful to policy responses. It was also confirmed by **Study 3** that designated agricultural land generally experiences lower conversion rates to urban uses than non-designated agricultural land, and the mean ALCU increased by 4.47%. Overall, formal recognition of farmland provides more stability than non-designated farmland, but its effectiveness depends on transparent regulations and financial incentives that motivate farmers to keep their land for crop production.

Conclusions

This study has examined how land consolidation, adaptation to drought, and land tenure security interrelate and affect the sustainability of farmland. This research synthesizes findings from a comprehensive meta-analysis and recent literature, providing essential insights into the dynamics of agricultural land use and offering practical recommendations for policy and practice.

Scientific contributions and key findings

Land fragmentation often causes increased soil erosion, inefficient land use, and overexploitation of resources. The findings of this study showed that land consolidation can reduce these pressures by enabling better land management practices, such as creating larger fields for easier cultivation, conservation tillage, and mechanization. For example, studies in China and many European countries have shown that consolidated land units foster long-term investments in soil health and incorporate measures for nature conservation, erosion control, and sustainable water management. From a scientific point of view, these insights add to the growing body of evidence that land consolidation is both a socioeconomic and environmental strategy. It enhances the spatial structure of agriculture in a way that supports ecological sustainability, especially when combined with regulations and governance structures that promote long-term land management.

In terms of minimizing the impact of drought events and improving farming system resilience, this study suggested implementing adaptation strategies, such as improved water management, drought-resistant crops, and soil conservation techniques. However, their efficacy varies significantly between farming systems. Traditional and organic systems frequently utilize indigenous knowledge and biodiversity to mitigate climate shocks, whereas conventional systems employ technologically advanced methods. However, achieving such objectives necessitates context-specific techniques for effectively mitigating drought effects. As a result, as our study demonstrated, there must be a worldwide interest in and recognition of the importance of studying drought events across multiple regions.

This study contributed significantly to the empirical investigation of land tenure security and its impact on agricultural land conversion to urban use. The meta-analysis of global studies revealed that tenure security, measured through variables such as tenure type, legal status, cadastral assignment, and land ownership, has a profound effect on ALCU and has the potential to substantially reduce its level. As supported by the findings, to preserve agricultural land and avoid the negative social and environmental effects associated with ALCU, land use policies should prioritize supporting owner-operated farming, land titles, private land ownership, and agricultural land designation. However, financial limitations typically prevent the implementation of land tenure security policies, especially in underinvested areas. To address this, there is a need for resource allocation and external financial support in maintaining effective land tenure measures.

Policy implications and direction for future research

This study provides policy implications for farmland sustainability, land use planning, and climate adaptation strategies. For example, formalizing land rights through cadastral mapping, titling, and legislation that safeguards owner-operated farms should be the highest priority for governments and international organizations. To promote tenure security through community engagement, it is also necessary to directly involve local communities in land governance. Moreover, it is essential to incorporate community-led resource management initiatives, participatory land mapping, and regular consultations within land use policy frameworks to align policies with local practices and requirements. Climate adaptation strategies should be integrated into agricultural policy through targeted subsidies, capacity building, and research investments. For example, supporting community-led water conservation initiatives and drought-resistant crop varieties can increase resilience, particularly among smallholder farmers. Governments also can help farmers adapt to climate change and drought impacts by encouraging organic agriculture and promoting organic techniques through agricultural research and extension systems. Then, national agricultural extension systems must disseminate knowledge, and technologies appropriate for local climatic conditions and agricultural practices. In terms of land consolidation initiatives, the programs should be strategically promoted to tackle the inefficiencies of fragmented landholding. As supported by the findings of this study, land management measures have a consistent positive effect when they are specifically targeted, and there is also a notable synergy between the effects of these measures. Therefore, land consolidation should be combined with environmental safeguards, such as including measures for nature, soil, and water conservation to maximize both productivity and sustainability.

Our study also paves the way for future research. Future studies should investigate the extent and consequences of land degradation caused by agricultural land conversion,

as well as ways to mitigate land degradation through land tenure security strategies. Future research can shed more light on a development-based perspective on adaptation measures at various scales and sectors, including agriculture, to reduce farmers' vulnerability to drought events. Lastly, more studies on the effect of land consolidation and land management measures on land degradation must be conducted in various natural and socioeconomic conditions.

As the final remark, protecting agricultural land is more important than ever in an era of rapid climate change and urbanization. This study emphasizes the important role that land tenure security plays in shaping farmers' decisions and resisting the current trend of land conversion. Tenure security is the foundation of sustainable agricultural landscapes combined with practical adaptation strategies and proper land consolidation policies. Integrating land tenure reforms with land-use planning and climate adaptation provides a practical framework for policymakers, researchers, and practitioners to ensure that agriculture is sustainable, resilient, and equitable for future generations.

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