UNDERSTANDING RESILIENCE OF AGRICULTURAL SYSTEMS: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Resilience is a widely studied concept that is a key objective in the design and development of sustainable systems. This is especially true for the agricultural systems critical to food production, economic viability, and sustainability of our communities, as farmers seek to meet increasing demand in the face of shocks such as climate change and natural disasters. Although there is a rich body of work examining resilience, there is limited understanding of how the concept of resilience should be tailored for agricultural systems. This study seeks to address this gap by performing a systematic literature review of 50 papers selected from SCOPUS using the PRISMA protocol. A summary of research topics and characteristics by geographical region is presented. The paper also categorizes the types of shocks studied and the corresponding response methods. Results suggest that the focus of resilience research changes by region, which may indicate that design strategies and objectives should also differ by region. Furthermore, the work identifies a need for more simulation-based quantitative research into the impact of resilience.

Keywords: Resilience, Agricultural Systems, Sustainability, Robust design, Simulation

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Cite this article: Boahen, S., Oviroh, P. O., Austin-Breneman, J., Miyingo, E. W., Papalambros, P. Y. (2023) ‘Understanding Resilience of Agricultural Systems: A Systematic Literature Review’, in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.371

https://doi.org/10.1017/pds.2023.371 Published online by Cambridge University Press

1 INTRODUCTION

Consistent with the UN Sustainable Development Goals for the conservation of land, water, and other resources (Nhamo, 2019), research on Integrated Natural Resource Conservation and Development (INRCD) projects employs a system design optimization approach to promote the economic development of local communities consistent with conservation of natural resources (Barlow et al., 2021). A recent review identified the use of quantitative tools that support decision-making as an important factor for project success (Rajski and Papalambros, 2021). Here we focus on INRCD projects related to agricultural systems, specifically small farming communities in Africa. These socio-technical systems are very important for food security in the global community.

INCRD-OPT is a simulation-based system design optimization tool for modeling and optimization of integrated irrigation, microgrid, and crop cultivation projects in small landholder farming communities often referred to as the Water-Food-Energy (WEF) Nexus (Albrecht *et al*., 2018; Oviroh *et al*., 2023). A key aspect of the INRCD modeling framework is the integration of engineering design decisions with the socio-economic needs and benefits of the farming communities. Specifically, system optimization objectives can be overall profit or a sustainability index (Oviroh *et al*., 2023). An important socio-economic need for farming communities is their resilience in the face of natural disasters and hardships related to climate change (Perez *et al.*, 2015). It would be desirable to integrate the concept of resilience for INRCD projects in a quantitative tool such as INRCD-OPT, for example as a system objective function to be maximized.

The concept of resilience has gained significant attention among researchers due to the increasing occurrence of natural and human-induced disasters worldwide. The term ‘resilience’ refers to the ability of a system to adjust, withstand and rapidly recover from shocks (Hoiling, 1973). In this definition, ‘system’ refers to the object affected by shocks such as engineering, economic, supply chain, social, or agricultural systems. ‘Shocks’ refer to events that disrupt system operation, and they can be external such as climate change, earthquakes, pandemics, political instability, wars, and riots, or internal such as human errors or technology failures (Spiegel *et al.*, 2021). System ‘ability to adjust, withstand and rapidly recover from shocks’, also referred to as *system capacities*, relates to system properties such as robustness, adaptability, and transformability (Meuwissen *et al.*, 2019). In other words, while resilience refers to the ability of a system to continue its performance in the face of a shock or disaster, resilience capacity is the ability of the system to anticipate, adjust and recover from the shock. The properties characterizing a resilient system are called resilience attributes. An important question is how the concept of resilience can be translated into an operationally useful, quantitative definition that can be used in INRCD project optimization. This paper seeks to explore how the extant research addresses this question through a systematic literature review according to the PRISMA protocol (Moher *et al.*, 2016).

Agricultural systems are particularly affected by shocks, especially those induced by climate change, such as droughts, floods, heat waves, hurricanes, and severe winds, posing a serious threat to food security and raising concerns about their resilience, see e.g., the report of the EU Commission (2020). Although the subject of resilience has been widely studied, understanding of the adoption and application of resilience to agricultural systems is lacking (Ahmadi *et al.*, 2022; Al-Haidous *et al.*, 2022). Concerning small farming communities, this paucity of studies is even more pronounced. This paper seeks to expand the understanding of resilience in agricultural systems through a systematic literature review.

More specifically, this review paper explores how the research literature addresses the following questions:

1. What resilience *methods* (e.g., adaptable, robust or transformable) farmers in different geographical regions use to mitigate the effect of shocks on their farms?
2. What resilience *research* on agricultural systems has been undertaken in different geographical regions (and how does it match the methods above)?
3. What operationally useful quantifications of resilience have been proposed and applied to agricultural systems?
4. What concepts of resilience have been studied for small farming communities?

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Table 1. Document review selection process segments

Segments	Query	Number of Documents
1	"Resilience AND Farm"	1962
	"Resilience AND Agriculture"	4543
	(Resilience AND Agriculture) AND (Resilience AND Farm)	750
	Refine search	
2	Publications from 2013 – 2023	668
	Subject Areas: Environment, Agriculture, Engineering, Energy	560
	Document Type: "Article and Review"	479
	Keywords: Agriculture, Climate change, sustainability, Resilience, Farming system	324
	English Documents	323
3	Review Title and Abstracts of Papers	50

The remainder describes the methodology used in the review and provides results and discussion on the above questions.

2 METHODOLOGY

We initiated the review using the PRISMA protocol (Moher *et al.*, 2016). The search was run on the Scopus database (Scopus, 2022). Scopus was selected because it contains articles from Agricultural Sciences, Engineering, Social Sciences, Environmental Sciences, and Sustainability. The search focused on articles published in English in the years 2013 – 2022.

Table 1 summarizes the selection process which was divided into three segments. In Segment 1, the query "Resilience AND Farm" was searched, yielding 1,962 documents, followed by the query "Resilience AND Agriculture" which yielded 4,543 documents. A combined query of the two was then performed, yielding 750 documents. Segment 2 refined the 750-document selection according to publication period, subject area, document type, keywords, and documents published in English, yielding 323 documents. Segment 3 reviewed the titles and abstracts of the 323 documents to eliminate articles that did not fall into the selection criteria, further reducing the documents to 50. The articles eliminated include those that were duplicated, out of scope, had single thematic areas, and those with only abstracts available. The 50 selected papers were then analyzed according to the year of publication, regional demographics (Africa, Antarctica, Asia, Australia, Europe, North America, and South America), the definition of resilience (supply chain, engineering, ecological, socio-ecological, agro-ecological), resilience capacity (robustness, adaptability, and transformability), and attributes of resilience. Recall that attributes refer to a set of activities or conditions created to ensure resilience. Terminologies, such as cover-cropping, mulching, crop insurance, describing the attributes needed to ensure resilience of the farming systems were standardized and used as a guide to collect data from the articles. Papers on activities that did not affect the output of the farm were classified in the robust category. This included activities such as insurance, investments, diversifying income sources, joining cooperatives, building buffers, etc. Papers on changing the farm's inputs and production by introducing new crops, energy or irrigation systems or using new planting methods were classified in the adaptable category. Papers on changing the entire farming system to stay resilient were classified in the transformable category. The information collected from these articles was placed in a Microsoft Excel file and analyzed (Boahen *et al.*, 2022). The 323-paper collection that were downsized to 50 can be revisited if the information from the selected 50 papers is insufficient to answer the research questions stated in the introduction.

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3 RESULTS AND DISCUSSION

In this section, we discuss findings regarding research by geographic region, types of studies reported, types of resilience by region, shock distribution by region, resilience capacity distribution by region, and resilience methods correspondence to different shocks.

3.1 Resilient farming systems research by region

The number of resilient farming systems studied according to different regions is shown in Figure 1. Region, as used in this work, refers to the continents from which these studies were done. Europe had the highest number of 16 studies reported on resilient farming systems, followed by Asia and Africa with 13 studies each. North America had 6 studies reported, one study was reported from South America while no study was reported from Australia. There was about 6% difference between the reported studies in Europe and those from Asia and Africa. The studies from these three regions show that intense efforts are being made to understand resilient farming systems and to develop resilient methods to mitigate the shocks affecting farms in these regions. A single study from South America shows that there is a need for research awareness on resilience farming systems in that region. It is also surprising that no study reported on resilient farming from the Australian region. Australia has a vibrant and research-oriented agricultural sector that does lots of work on precision agriculture and modern agricultural technologies (Bramley and Trengove, 2013). However, there seems to be no focus on the development of resilient agricultural systems or policies to mitigate the effect of shocks, especially climate change, on the future of the agricultural sector in that region.

3.2 Types of studies

Figure 2 shows the different types of methods used in studying the resilient farming systems reported in the papers reviewed. About 70% of the papers were cross-sectional studies, where questionnaires and interviews were used to understand resilience farming systems from the perspective of farmers. Cross-sectional studies are used to analyze data from a population at a single point in time through observation. The strengths of cross-sectional studies stem from the fact that they are relatively faster and cheaper to conduct, they help to easily formulate a hypothesis on a subject being investigated, and they could be used to collect data on different variables at the same time. However, cross-sectional studies cannot measure a parameter being investigated or clearly explain the cause of action (Wang and Cheng, 2020). The results from such studies are best used as the foundation for further studies using experimental or computational modeling methods. Nonetheless, just about 4% and 6% of the studies reviewed focused on experimental studies and computational modeling, respectively. Compared to experimental studies,

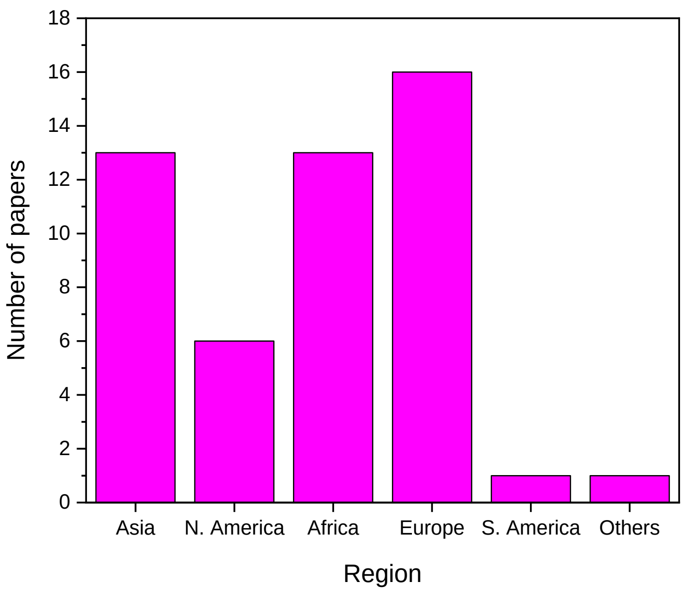

Figure 1. Number of studies on resilient farming systems report according to regions

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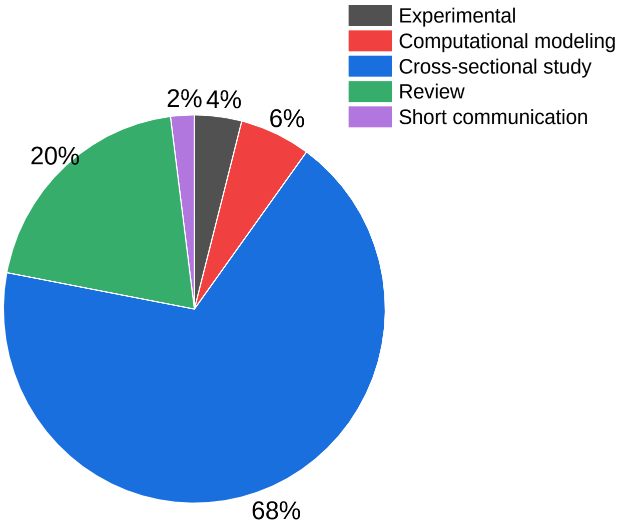

Figure 2. Study types of the papers used for the systematic review

computational modeling is inexpensive and useful, especially in areas that lack research funding. Nevertheless, highly skilled persons are needed to be able to accurately develop computational models for real systems. This might be the reason for the lower studies reported using computational modeling as compared to cross-sectional studies, since the study field is agriculture and the background of most of the paper authors are from the agricultural sector (Mangaza *et al*., 2021; Nasr *et al*., 2021; Wongnaa and Babu, 2020). However, the agricultural sector is increasingly technologically driven. Moreover, the associated problems in the sector are multi-disciplinary and their solutions require expertise from different fields, including system design engineering. Computational modeling has been used in the design and analysis of resilience systems in the building, marine, and industrial sectors, and can be applied to resilient agricultural systems as well.

3.3 Types of farming resilience by region

The regional distribution of the types of resilience found in the papers reviewed is presented in Figure 3. The types of resilience reported by farmers in the reviewed papers include socio-ecological resilience, supply chain resilience, agro-ecological resilience, and livelihood resilience. The ability of a socio-ecological system, supply chain system, agro-ecological system, or of a community at large, to recover its original state or to shift towards a better state after encountering a shock is referred to as socio-ecological resilience, supply chain resilience, agro-ecological resilience, or livelihood resilience respectively (Adams *et al*., 2015; Emenike and Falcone, 2020). Socio-ecological resilience was dominant across all the regions due to the interconnected relationship between agricultural systems and society, such that anything that affects the agricultural system directly affects the living conditions of society. Europe had a fair distribution of all four resilient types, even though supply chain resilience, agro-ecological resilience, and livelihood resilience occurred a few times. This shows that farmers in Europe understand the dangers of shocks in every aspect of the agricultural value chain and are making conscious efforts to preserve and sustain not only their farms but their entire livelihood. All studies from North America considered socio-ecological resilience. Since most of the papers used cross-sectional studies, the report of socio-ecological resilience from all the papers in North America might be because the farmers interviewed in these studies are mostly interested in how the disturbances and shocks affecting their farms directly affect their food and pocket. Different approaches, such as experimental studies and computational modeling of the resilience in farming systems in North America may show other types of resilience. Farmers from Asia and Africa reported similar distributions of the type of resilience affecting their farming systems while the distribution of the type of resilience reported by farmers in South America is a reflection that not much research is being done on resilience farming in that region.

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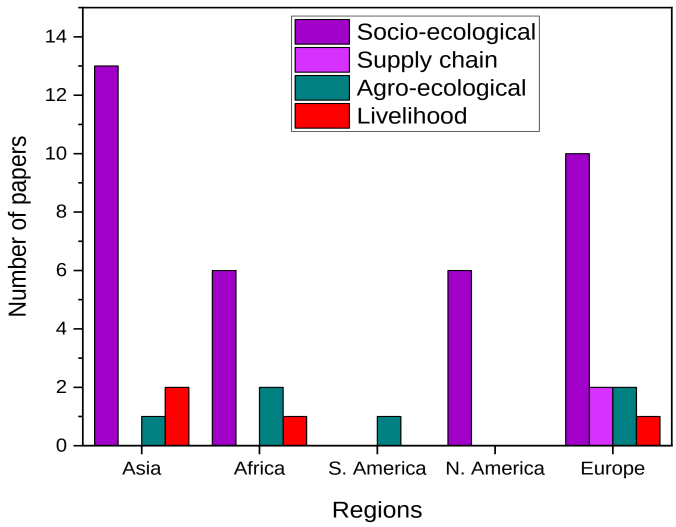

Figure 3. Regional distribution of the types of resilience studied

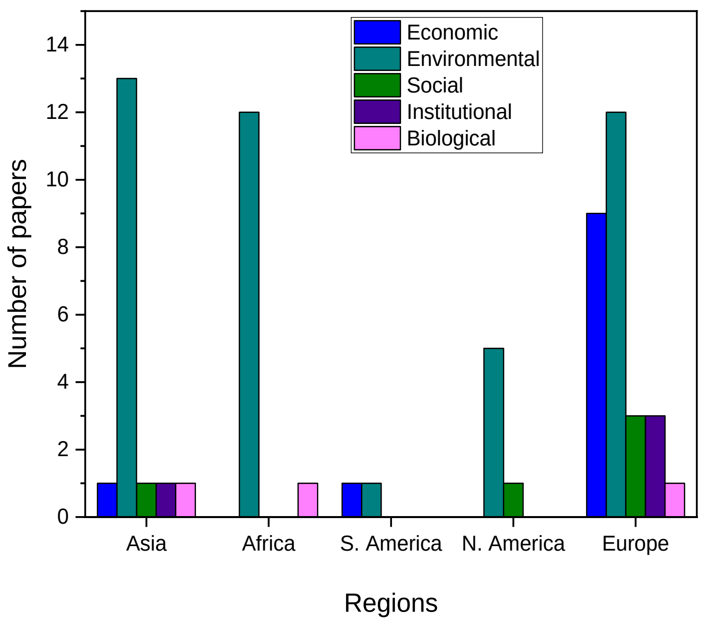

Figure 4. Regional distribution of shocks affecting farms

3.4 Regional distribution of shocks

Figure 4 shows the shocks suffered by the farming systems in the regions reported in this study. Environmental shocks were prevalent in the farming systems reported in all the regions studied except South America. There was an even distribution of shocks reported by farmers in Europe such as trade wars, extreme weather conditions, reduced access to markets, price volatility, pest infestation, and COVID-19 (Meuwissen *et al.*, 2020). These shocks affect the agricultural sector and pose major resilience problems that farmers need to handle. Farming systems in Asia and Africa were predominantly affected by environmental disturbances that also breed pest infestations. Most countries in Africa and Asia are developing countries that are faced with economic, social, and institutional challenges. However, the studies reviewed were not reflective of these challenges on farms in those areas. Most of the studies from North America were reported on farms in the USA, a highly industrialized country. This might be the reason for the shocks in that region being predominantly environmental. This does not mean that farms in the USA are not affected by other shocks, however; it may just mean that environmental shocks are of much concern to the farmers.

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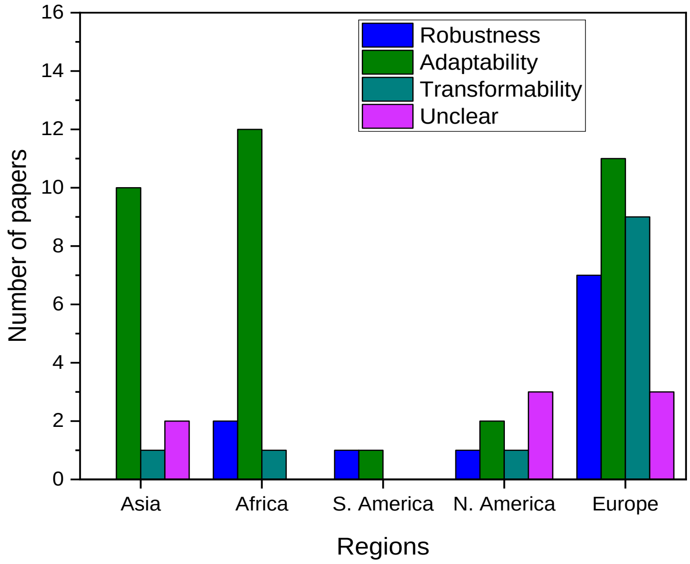

Figure 5. Regional distribution of resilience capacity

3.5 Regional distribution of resilience capacity

The regional distribution of resilience capacity from the reviewed papers is shown in Figure 5. Robustness, adaptability, and transformability were the resilience capacity identified. Robustness denotes the farm's ability to continue operating in the face of a shock without any effect on the output of the farm. Adaptability is the ability of the farm to change its inputs, marketing, risk management, and production as a response mechanism to shocks without compromising on its basic structures, while transformability denotes changing the existing farm into a new farming system with a new structure and feedback mechanism in response to a shock (Benabderrazik *et al.*, 2022). As found in the reviewed studies, farmers perform activities such as building financial buffers, crop insurance, diversification of income sources, investment, seeking farmlands in other places, and seeking assistance from cooperative unions and agricultural extension officers to ensure the robustness of their farms. Crop management, livestock management, land and soil management, and water management practices are practiced by farmers to ensure adaptability, while farmers change a farm type such as a mixed crop to a new farming system such as livestock or cash crop to ensure transformability. European farmers reported an even distribution of the resilience capacity with adaptability as the most frequent. Farmers from North America also adopted all resilience capacity even though the frequencies were small due to the lower number of studies from that region. However, farming systems in Asia and Africa predominantly practiced adaptability because it is inexpensive and the tools are mostly accessible compared to robust practices that might not be readily accessible, and transformable activities that may be expensive to the farmers. In all, this study shows that adaptability is frequently practiced among farmers in their quest to build resilient farms. However, the missing link is whether these adaptable practices result in higher crop yields and income. There is a need to quantify these adaptable resilient practices and their corresponding effects on farming systems to provide farmers with the right framework to select the best resilience capacity suitable for their situation.

3.6 Shocks and corresponding resilience methods

Table 2 summarizes various shocks reported by farmers and the corresponding resilience methods they use to mitigate them. The economic shock farmers spoke about was the rising costs of farm inputs. To ensure the robustness of farms in the face of unfavorable price hikes, farmers diversify their income sources, build buffers, invest or join agricultural cooperatives to get farm inputs at reduced prices. Farmers introduce new crops and practice low-input farming as adaptation measures to respond to economic shocks. Environmental shocks, caused mainly by climate change, such as drought, flooding, and heat waves were the predominant shocks reported by farmers. To ensure robustness in the face of these environmental shocks, farmers insure their crops, secure credits and loans, change the crop

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Table 2. Shocks and the corresponding resilience method

Shock		Resilience Method		
Type of shock	Detail	Robustness	Adaptability	Transformability
Economical	Price volatility	○ Diversify income source ○ Build a buffer ○ Invest ○ Be involved in cooperatives	○ Introduce new crops ○ Practice low-input farming	○ Change farm type
Environmental	Climate change *(Drought)*	○ Insure crops ○ Secure credits and loans ○ Change planting and harvesting time	○ Build boreholes, dams, and rainwater harvesters or irrigation systems ○ Install energy systems (Solar PV) ○ Plant drought-resistant crops	○ Change farm type
	Climate change *(Flooding)*	○ Insure crops	○ Plant flood-resistant crops ○ Practice intercropping	
	Climate change *(Heat Wave)*	○ Change working hours	○ Decrease livestock stocking density ○ Plant high-quality seeds ○ Plant on the nursery ○ Install irrigation systems ○ Diversify livelihood	
Social	Pandemics *(COVID-19)*	○ Be involved in cooperatives		
Biological	Pest infestation	○ Fallow periods ○ Change planting and harvesting time	○ Use Pesticides	

planting and harvesting time, and change their working hours on the farms. The adaptation measures employed by farmers to respond to environmental shocks include the building of boreholes, dams, rainwater harvesters, and irrigation systems to provide crops with the needed water requirement. Energy systems, such as solar PV systems, are also installed on the farms to provide energy for the irrigation systems, while drought-resistant and flood-resistant crops are cultivated to respond to droughts and floods respectively. Farm management practices such as intercropping, decreasing crop and livestock stocking density, and planting high-quality seeds in a nursery are also used as adaptation measures to environmental shocks. Furthermore, farmers respond to social shocks by joining agricultural cooperatives to receive financial, technical, and supply chain supports. They also allow their farms to go through fallow periods or change the crop planting and harvesting time to adapt to biological shocks. For all shocks, farmers reported that they change the farm system to achieve transformability.

These resilient methods provide a pool of options available to farmers to select a method that will ensure the robustness, adaptability, and transformability of their farms. Nonetheless, this pool does not provide enough information for the farmer to decide on the right resilience method that would result in

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higher crop yield, profit, and farm sustainability. Farmers will always be concerned with the cost involved in selecting a particular resilience method and the profit or crop yield it will provide. There is, therefore, a trade-off between the cost involved in implementing a resilient method and the corresponding profit that comes with it. This trade-off points to the need for resilience optimization and the adoption of system design thinking.

4 CONCLUSION

This study offered a systematic literature review to understand the resilience methods farmers use to mitigate the effect of shocks on their farms and the associated research work. To this end, 50 research papers were down-selected and their contents were summarized according to geographic regions. Shocks affecting agricultural systems and the corresponding resilience methods employed by farmers to mitigate these shocks were categorized. The study found that farmers in Europe use robust, adaptable, and transformable resilience methods to respond to shocks, while farmers in Asia and Africa predominantly use adaptable resilience methods. However, more studies are needed to be able to understand the resilience methods used by farmers in South America and North America. Further, the research focus was found to differ from region to region. Studies reported from Europe focused on the use of robust, adaptable, and transformable resilience methods in response to economic, environmental, social, and biological shocks. These resilience methods were used to ensure socio-ecological resilience, supply chain resilience, agro-ecological resilience, and livelihood resilience. Studies reported from Asia and Africa predominantly used adaptable resilience methods in response to environmental shocks to ensure socio-ecological resilience. Studies reported from North America focused on the use of robust, adaptable, and transformable resilience methods in response to environmental and social shocks to ensure socio-ecological resilience. The research focus in the South American region was not clear since very few studies were reported from that region. Nonetheless, these differences in the regional research focus on resilience suggests that the design strategies or objectives of resilient agricultural systems would differ according to the region.

Additionally, about 70% of the reported studies were cross-sectional studies, 20% were review studies, 6% were on computational modelling, and 4% were experimental studies. In general, cross-sectional studies are unable to quantify the effectiveness of the resilience methods used. Further studies using experimental and computational modeling techniques will be helpful to understand, quantify and suggest the right resilience methods that can respond to a particular shock to ensure higher crop yield, profit, and sustainability of the farming systems.

No resilience quantification methods were used by farmers or the researchers in the papers studied, and the resilience methods discussed in the papers were not specific to farm size. Therefore, the relevant research question posed in the introduction has not been answered and further detailed analysis of the larger 323 paper collection must be undertaken next to explore further how the questions posed in the introduction can be answered more fully, especially for small-scale farming systems.

ACKNOWLEDGMENTS

This work was partially supported by the Donald C. Graham Endowed Chair and the African Studies Center at the University of Michigan. This support is gratefully acknowledged.

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