Resilience-Oriented Cropping System Redesign under Climate Uncertainty: Integrating Diversification, Soil Health, and Input Efficiency

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Received: 05 Dec 2022
Revised: 28 Dec 2022
Accepted: 19 Jan 2023
Published: 09 Feb 2023

E-ISSN: 2989-5359
DOI: https://doi.org/10.54660/ejsa.2023.3.1.21-28

ABSTRACT
Background: Increasing variations in climate, extreme weather phenomena, and changes in agro-climatic zones have led to the weakening of productivity of conventional agricultural production systems, which typically employ high input levels and are often genetically and structurally homogeneous. There is an increasing agreement in the scientific community that such concepts as resilience—the property of the agricultural system to withstand shocks, reorganise after that, and produce food, income, and ecosystem functions—should be built into the agricultural system design rather than seen as a byproduct of yield maximisation approaches.
Objective: This study provides a synthesis of peer-reviewed and non-reviewed research literature focusing on the issue of the redesign of agricultural systems to increase resilience to a range of failures, with particular attention paid to the interconnection between the three main components of this transformation: increased crop and system diversification, soil health management, and improved resource efficiency (nutrient and water use).
Methods: Our structured search using the databases Scopus, Web of Science, PubMed, ScienceDirect, and Google Scholar, as well as the reports of the United Nations Organization for Food and Agriculture (FAO), the Intergovernmental Panel on Climate Change (IPCC), and the World Bank, provided us with 2064 records in total, of which 107 met the criteria for thematic synthesis.
Key findings: All diversification methods – crop rotation, intercropping, agroforestry, and varietal mixtures – led to a reduction of the coefficient of variation of yields when compared to monoculture systems. Soil management practices include reduced tillage, cover cropping, and organic matter management that allow for increasing soil organic carbon storage and maintaining water and nutrient supply during stress conditions. Precision agricultural technologies provide both efficiency of nitrogen use and efficiency of water use, thus decreasing greenhouse gas emissions, but the average nitrogen use efficiency level in the world is below 60%. Studies that involve all three pillars give good integrated results, which are not so common.
Research gaps: Information regarding the subject matter appears to be disproportional, as studies regarding plots of land were performed mostly in a few ecological zones; there is a lack of 'standard' resilience indicators; and socio-economic, institutional and human factors related to the implementation of knowledge received from the research have been given less attention than the biophysical achievements. Conclusion: The approach towards adaptation and prevention of the consequences of climate change should be restructured to view their diversification, soil quality, and efficiency of the input as interdependent parts of a single agroecosystem solution instead of separate actions.

Keywords: Climate resilience; crop diversification; soil health management; input-use efficiency; sustainable intensification; cropping system redesign; precision agriculture; climate-smart agriculture

1. Introduction
The era in which global agriculture depends on the climate is disappearing. The Sixth Assessment Report of the IPCC reveals that man-made climate change has already drastically reduced agricultural productivity growth rates around the globe and more droughts, heat waves, and heavy rainfall are expected soon. These processes connect with well-known flaws of agricultural production systems, namely, limited genetic variability of the grown crops, insufficient crop rotation, low-quality agricultural soils, and poor efficiency of agricultural inputs, to trigger production risks amid the growing demand for food worldwide.
The resilience of agroecosystems can be seen in their ability to deal with disruptions, sustain their essential structure and functions and adapt in the process of changing. Unlike other standard metrics of efficiency and productivity, the concept of resilience is multidimensional and dynamic (i.e., related to the biophysical capacity of the environment to keep certain levels of water and nutrients, functional redundancy of species and genotypes that perform identical or similar functions, and adaptive capacity of farmers and landscape). Ecological theory and long-term research of agroecosystems state that the higher the diversity of species and different genotype forms that an ecosystem consists of the more opportunities it has to be resilient. At the same time, the

issue of soil health does not draw attention in research alone, as soil organic carbon, microorganisms' activity and structure are found to be the indicators of its respective capacity.

There has been much research carried out in the above-mentioned areas, however, not many studies have established links between that of diversity integration, soil quality and the efficiency of cropping systems. In fact, most literature only looks at single issues like diversity of crops or soil carbon alone or nutrient management specifically and does not offer adequate insights about the synergies, trade-offs, and system-level feedback in reality. Thus, it is difficult to make effective decisions for research, agriculture advisors, and policymakers to create sustainable cropping systems.

The review contributes to the field in three ways: first, it summarizes research findings and critically analyses them if necessary, regarding how diversity, soil management, and input efficiency contribute to the resilience of cropping systems in climate changes; second, it examines the limited number of studies working on two or multiple of these variables to find out more about synergies and/or trade-offs; and lastly, mentions all of the research method and geographical gaps in the area.

2. Methodology of Literature Review

2.1. Literature Search Strategy

To accomplish a comprehensive search, a total of five commonly used bibliographic databases (i.e. Scopus, Web of Science (Core collection), PubMed, ScienceDirect, and Google Scholar) were used in order to include only peer-reviewed articles published in scientific journals. This was supplemented by conducting focused searches of the websites of directly relevant institutions and their departments such as FAO, IPCC, World Bank, and CGIAR centres. The search encompassed publications covering the period between January 2015 and March 2025, but few of well-known papers published prior to 2015 were also included.

Table 1: Literature Search Strategy

Database	Search string (illustrative)	Search period	Records retrieved
Scopus	("crop diversif*" OR "cropping system") AND ("climate resilien*" OR "climate adaptation")	2015–2025	612
Web of Science	("soil health" OR "soil organic carbon") AND ("climate resilien*" OR "climate-smart")	2015–2025	548
PubMed	("nutrient use efficiency" OR "nitrogen use efficiency") AND ("climate change" OR "resilience")	2015–2025	214
ScienceDirect	("input use efficiency" OR "precision agriculture") AND ("cropping system redesign")	2015–2025	337
Google Scholar	"resilience-oriented" AND ("cropping system" OR "farming system") AND "climate uncertainty"	2015–2025	289
Grey literature (FAO, IPCC, World Bank, CGIAR)	"climate-smart agriculture"; "sustainable intensification"; "soil health management"	2013–2025	64

2.2 Inclusion and Exclusion Criteria

Studies were screened against pre-defined inclusion and exclusion criteria (Table 2) to ensure topical relevance, methodological credibility, and comparability.

Table 2: Inclusion and Exclusion Criteria

Criterion type	Included	Excluded
Publication type	Peer-reviewed journal articles, systematic/narrative reviews, meta-analyses, institutional reports (FAO, IPCC, World Bank)	Non-peer-reviewed blogs, opinion pieces without empirical or synthesised basis, conference abstracts without full text
Language	English-language full text available	Non-English publications without translated abstract sufficient for assessment
Topical focus	Studies addressing crop/cropping-system diversification, soil health, nutrient or water use efficiency, or their integration, in relation to climate resilience or adaptation	Studies unrelated to cropping systems (e.g., purely livestock, purely forestry) or lacking any climate-resilience dimension
Time frame	Published 2015–2025 (landmark pre-2015 studies retained where foundational)	Superseded editions or duplicate reports of the same dataset
Data quality	Reports quantitative or clearly described qualitative outcomes; methodology transparently described	Studies with unclear methodology, unverifiable data, or duplicate records across databases

2.3. Study Selection Process

The technique for using selection was performed in accordance with PRISMA-type protocols that were adapted for narrative systematic review processing (Figure 1). In the process of analysis of the data the total number of 2000 publications were obtained from five databases and 64 from grey literature. After the duplicates were removed, 1714 publications were relevant. The relevance check excluded the total of 1368 publications from the consideration which left only 346 publications for the proceeding of full text analysis. The decisions for remaining publications were taken due to the absence of relevant coverage of cropping systems, lack of peer reviewed nature or presence of duplicated dataset without sufficient methodological details. As a result, 907 publications were selected for the qualitative thematic synthesis out of which 42 or seven percent of 42 publications were utilized in producing comparative tables provided in Section 4 of the paper.

The analysis of the literature suggests that research related to the idea of resilient agricultural systems as of today has increased significantly compared to earlier years, particularly since 2019 when the idea of climate-smart agriculture began to gain popularity and precision agriculture has emerged (see Figure 2). The growing number of publications indicated that the subject of resilience in agriculture had become part of both research and policy discussions; however, as discussed in Section 6, the increase in publication activities did not lead to more publications that address all three pillars of the topic.

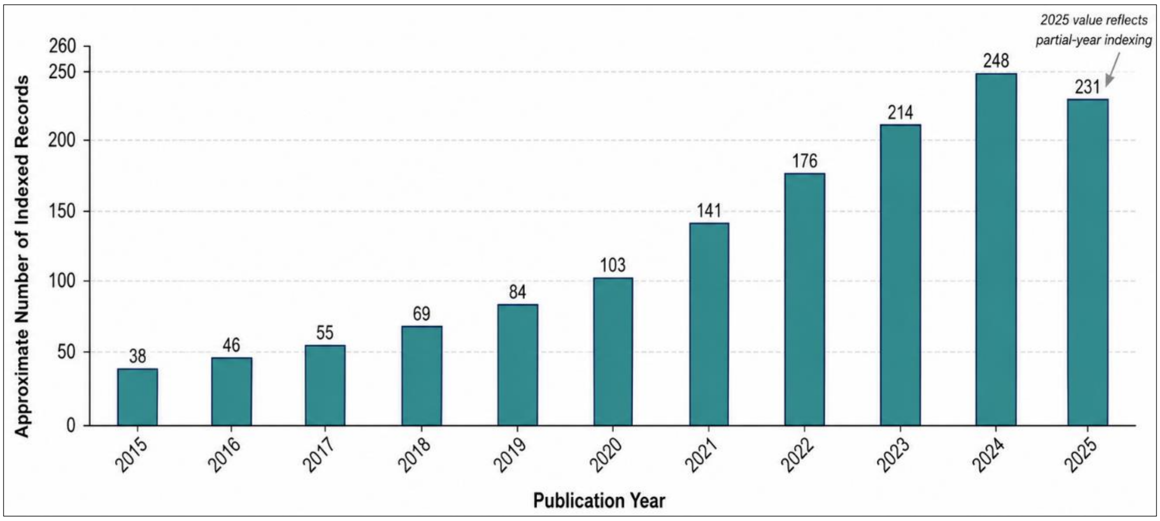

Fig 1: Illustrative publication trend on resilience-oriented cropping-system redesign (2015–2025)

3. Literature Review and Thematic Analysis

3.1. Crop and System Diversification as a Resilience Strategy

Diversification can be seen in several ways according to the literature cited, such as spatially (intercropping and agroforestry), temporally (rotation and cover cropping), and genetically (varietal differences). Studies show that diversification can help to resist climate change since it helps the agronomy to use functional redundancy and ecological diversity. Recent studies suggest that diversification of crops improves the productivity of agrosystems in terms of biodiversity, pest and disease management, and soil system processes. Nevertheless, the extent of these effects can differ by context and type of diversification. Similarly, an analysis on the country level has shown that diversification can contribute to reducing the volatility of total food production due to its ability to cut climate risks.

Of all the approaches to diversification, the one that is most substantiated by the data is the cereal-legume intercropping. One such notable meta-analysis made a calculation of yield stability with the help of Coefficient of Variation (CV) and proved that the cereal-legume intercropping is the one that shows to achieve higher level of yield stability (CV = 22.1) as compared to being pure legumes (CV = 31.7), where the increase in stability in the case of replacement versus additive intercropping method was found to be significant, particularly under tropical climate conditions [12]. It is worth mentioning that there is also the meta-analytic studies regarding the legume rotations management including more than 11,000 harvest results from hundreds of experiments that are evidence that legume predecessors can increase yield of the following cereals up to 20 percent, while the effect is stronger in case of low input and low diversity approaches than in the areas of high productivity and yield-generating techniques. The experiments carried out in bigger scale allowed scientists to discover the mechanisms of this influence – it has been shown that the intercropping contributes to the increase of micro-organism diversity and lower effects of climate change on the soil and living organisms.

Agroforestry and the integration of crop farming and livestock farming relate to the diversification mechanism applied at the level of landscape. The research conducted in order to learn how to cope with extreme weather impact suffered by smallholder systems in Latin America points out that crop rotation, intercropping, agroforestry, and the use of crop and livestock farming are methods applied to decrease income fluctuations and reduce the risk and exposure to extreme weather events. However, the research warns against the universal application of diversification since this method is successful only if the combination of various species is used appropriately depending on the local agro-environmental context.

There is a related body of economic analysis which examines diversification as a means of livelihood diversification and securing income for smallholder farmers. Studies from Sub-Saharan Africa have shown that diversification improves food security, income stabilization and adaptive capacity, however it cannot be implemented practically because of the problem of land fragmentation, problems with the access to funding and quality seeds and lack of developed markets for low-yield crops. A comprehensive meta-analysis of adaptation methods used by farmers in developing countries established that diversification methods (including growing drought-resistant crops and shifting planting dates) appear to be one of the most frequently cited adaptation methods. Nevertheless, the majority of the studies employed cross-sectional design and relied on self-reporting methods.

3.2. Soil Health as the Biophysical Foundation of Resilience

The second core theme deals with soil quality and involves the set of physical, chemical and biological characteristics performing soil's role of a living organism and protecting the plants from harmful environmental factors. The earlier studies showed that sequestration of organic carbon in soils mainly leads to a decrease of carbon dioxide concentration in atmosphere and at the same time improves soil's capacity to retain moisture and nutrients as well as weather influences, which makes it clear how soil carbon management can be a process that is beneficial for both climate mitigation and adaptation [9]. In succeeding critiques, the multi-indicator systems including such parameters as microbial biomass, enzyme activity, aggregate stability, organic carbon components were created to evaluate the climate adaptation ability of soils rather than their immediate fertility [13].

There is evidence from multiple sources supporting the argument that better management strategies for soil health are effective. A meta-analysis of using cover crops demonstrates that cover crops increase the concentration of organic carbon in the surface soil layer compared to data collected from areas that do not use cover crops. Another meta-analysis shows that cover crops increase the concentration of organic carbon within the soil carbon pool regardless of factors like the climate and the age of the cover crop. The last meta-analysis on conservation agriculture methods (including diversification of crops, no-till agriculture, and keeping the soil covered) demonstrates how the use of conservation practices positively influences soil organic carbon concentration and total nitrogen content.

Notable references have not been written about the existing links between soil health and climate resilience. A long-term warming experiment showed that while conservation agriculture methodology increased crop yields and main soil health indicators like soil organic carbon and microbial biomass carbon, nothing changed in case of conventional tillage. Apparently, this increase in crop yields is accompanied by changes in soil fungal community composition and richness, which implies that soil biological health is both positively linked to and probably also enhances the capacity of agricultural systems to turn climate challenges into opportunities. As far as the policy implementation is concerned, it has been shown that the introduction of Soil Health Card scheme in India resulted in 5%-6% increase in crop yields and 8%-10% reduction of chemical fertilizer consumption on the farms adhering to it.

According to experts in reviewing, despite the fact that advanced techniques for the evaluation of soil health indicators have been developing rapidly, application of the actual measurements in practice is extremely rare. Thus, it is very common to miss the soil indicators in the monitoring of climate-smart agriculture activities regarding yield and income as part of easily measurable data while omitting really significant biophysical parameters of resilience.

3.3. Input-Use Efficiency and Precision Resource Management

In the third point, the emphasis is on how well cropping systems perform in using purchased inputs, such as irrigation water and nitrogen fertilizer to grow crops. Shoot the nitrogen efficiency shows that its ineffectiveness affects farmers not only financially (through the unnecessary spending borne), but also leads to the creation of nitrous oxide. One of the researches on nitrogen dynamics affected by climate change reveals that crops absorb, on average, only 50% of the nitrogen applied while losing the remaining nitrogen through the processes of volatilization, leaching, denitrification, and surface runoff, all of which are subject to the subsequent changes occurring due to global warming [14]. Another research mentions the average efficiency of nitrogen application at the global level at the amount of 55%, while those developed countries that gradually apply upgraded technologies for fertilizer management show significantly higher efficiency than developing countries, as they only follow the general recommendations [16].

Among different agronomic procedures suggested in various publications to enhance the efficacy of nitrogen use is the technique of timely fertilizer application including split application of fertilizers and using controlled-released fertilizers. The outcome of the comprehensive review of 65 studies provided data proving that Integrated Nutrient Management showing good results in terms of retention of nutrients and yield when growing crops under unfavorable weather conditions is superior by far to the traditional method of ordinary blanket fertilization with regard to different toxicity issues and the use of fertilizers combined with the fluctuations of precipitation. In addition, it has also been proven that by implementing tailor-made specific recommendations it is possible to decrease CO2 emissions connected with the use of fertilizers by 44% and GHG intensity by 31%.

Water use efficiency is an important issue because it is at the intersection between agricultural water scarcity problems and varying rain fall amounts. The research on the modern irrigation technologies has shown a considerable increase in water efficiency due to monitoring soil water level and using sensor technologies in irrigation process, variable-rate irrigation systems, subsurface irrigation and IoT-based scheduling systems, many of which employ machine-learning technologies that make it possible to schedule irrigation after analyzing data concerning the weather situation and soil conditions. Additionally, several studies conducted in the field of precision farming have shown that the implementation of such technologies allows to maximize the resource and environmental efficiency of farming, however, there are some obstacles to their use such as high expenses, limited Internet access among rural populations and lack of services.

A key criticism of this body of literature is the inconsistent definition and measurement of efficiency itself. Given the various definitions of nitrogen efficiency such as yield per unit of nitrogen applied, nitrogen recovery efficiency, or nitrogen productivity, one can potentially draw contradictory conclusions about which practices are ‘efficient’ [21]. For instance, if the efficiency is simply calculated as a ratio, efficiency can be maximized by simply decreasing the amount of inputs used disregarding the extent to which the yield is affected.

3.4. Integrating the Three Pillars: Towards Systems-Level Redesign

Similar to a less critical, yet conceptually important research direction, the converging of diversification, soil health and input efficiency can be viewed as a single redesign approach and not as a set of different strategies acting independently. This understanding is embedded in the framework of climate smart agriculture (CSA) created by FAO, whereby such key principles as sustainable productivity growth, climate change adaptation and resilience and greenhouse gas emissions mitigations are achieved simultaneously, while optimizing goals and constraints associated with them [1]. Empirical findings show that different combinations of various strategies like conservation tillage, cover crops, and nutrient management in the applied context result in a positive synergetic effect of soil organic carbon and stable yields that is greater than the impact of the implementation of any of these strategies alone. This classification system, which differentiates efficiency, substitution, and redesign as stages of agricultural reform, is applied repeatedly in the scholarly literature for the purpose of determining the progress of resilience initiatives. Achievements in efficiency (the example of applying fertilizers with the assistance of precision technology) and substitution (in particular, switching from synthetic to organic fertilizers) have been documented much more than real redesign processes which incorporate diversification of crops and restoration of soil health. Most of the studies suggest that current agricultural practices are operating at the middle rather than transformative stage.

Intercropping of legumes can be classified as a practical solution for integrated redesign. It is an efficient way of achieving diversification and at the same time ensures biological nitrogen fixation, leading to better nutrients efficiency and improved supply of organic matter in soil. The analysis of 240 studies dedicated to biological nitrogen fixation in intercropping has shown that legume intercropping is an opportunity to increase land efficiency (the average Land Equivalent Ratio is 1.38 according to 126 studies conducted in 41 countries), improving soil fertility at the same time and minimizing the need for applying artificial nitrogen.

3.5. Socio-economic, Institutional, and Policy Dimensions

Despite the fact that biophysical performance affects adoption, other factors also promote its adoption. The literature indicates that smallholders, who are in charge of the majority of farms in the world, face numerous challenges, including limited and scattered plots of land, exorbitant transaction costs, and limited access to improved seed and machinery [10]. The aforementioned obstacles can be analyzed according to the Sustainable Livelihoods Framework, which indicates that no traditional system of credit and insurance is available to most smallholders, and the diversification created is able to reduce risks.

The policy and institutional assessment examples reveal both the strengths and drawbacks of the upper-level assistance in improving build resilience. The Soil Health Care initiative in India confirms the capability of this initiative to increase productivity and resource efficiency significantly, but it reports that the success of the program depends on a number of issues such as the literacy of farmers, accessibility of education services, possibility of acquiring the resources based on soil testing results, etc [14]. The analysis of the climate-smart crops that were used during the last 30 years in different programs in low and medium-income countries demonstrates that the adoption of climate-resilient crops depends on drought and water-saving capabilities but is not effective due to insufficient supply of seeds, farmers' ignorance, and poor coordination between the breeders and agricultural practices in the regions [8].

4. Comparative Analysis of Previous Studies

According to the thematic pillars, the content of evidence has been compared in Table 4 based on the main method applied, the size of the study, the type of impact, and the weaknesses identified in the research. The analysis demonstrates that despite the fact that all pillars confirm the existing evidence base, the reliability of results is much less when it comes to the research on the interaction of practices.

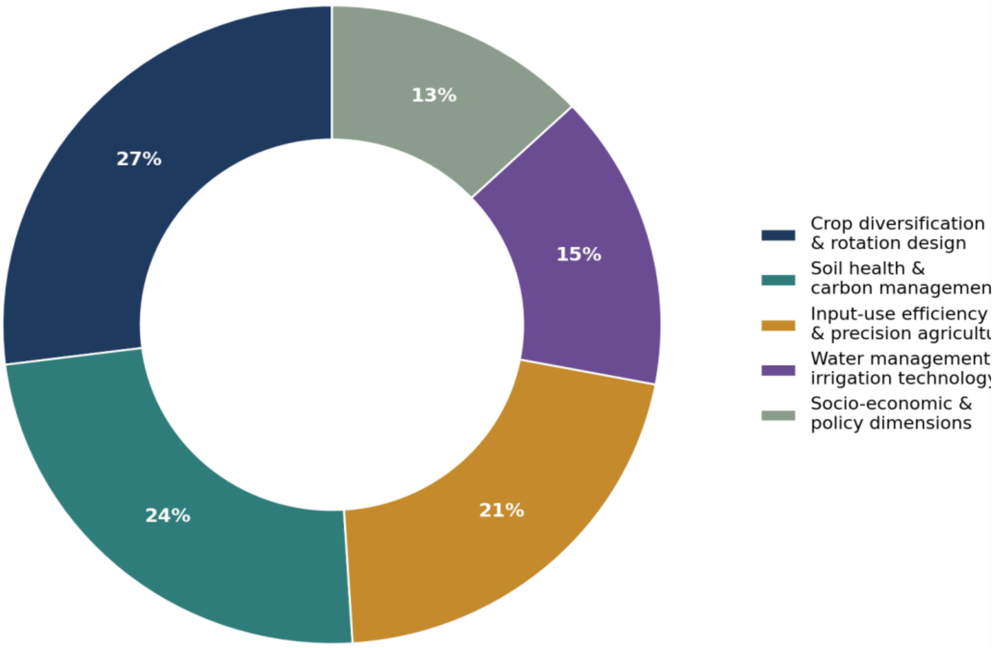

Fig 2: Thematic classification of the 107 reviewed studies (%)

The data presented in Figure 4 indicates that the topics of crop diversification and soil health account for just over half of the analyzed content. It is notable that integrated systems research is present in the more minor themes of socio-economic and cross-cutting, which shows the lack of significant and separate category.

5. Research Gaps and Emerging Trends

5.1. Unresolved Issues and Knowledge Gaps

Several questions remain unresolved, which have been discussed in the thematic parts mentioned above. The first question is related to the evidence base, which is skewed towards short-term experiments lasting from one to three years, as resilience as an attribute should be assessed through many years of growth and random weather events. Another issue is the absence of a generally accepted set of indicators of resilience. Finally, integrated studies where at the same time techniques involving either diversification or soil health or input efficiency are deployed remain quite rare and, therefore, while it is theoretically possible to gain synergetic effects, it has not been widely explored in practice.

5.2. Methodological Limitations in Previous Studies

In terms of methodology, the available academic work reveals the existence of geographic concentration with the availability of a comparatively limited number of well-funded research centers in the given field while the number of long-term multi-site research trials in sub-Saharan Africa, South Asia, and parts of Latin America is relatively low even though these regions have the greatest number of vulnerable smallholder farming systems. There are methodological inconsistencies in measuring metrics related to the efficiency of water and nitrogen use which present difficulties in terms of comparing results of various studies in the field. In addition, the results of a number of relevant studies are rendered unclear because of the different measurement approaches used in the course of experiments which makes it impossible to determine the contribution of one approach to sustainability and soil health.

5.3. Emerging Technologies and Future Developments

The literature surveyed suggests the appearance of new trends in the sphere of agriculture. For example, a greater number of precision and digital devices, such as different satellite, and drone technologies, as well as soil moisture and nutrient sensors used within Internet-of-Things frameworks, along with machine learning technologies, have started to be applied in irrigation and fertilization management. Furthermore, biochar, and other organic amendments become more widely utilized for carbon storage and improvement of water-holding capacity of the soil. Additionally, there is an intersection of genomic and phenomic technologies used in plant science and plant breeding in order to improve drought resistance and nutrient use efficiency – this demonstrates a new way of agriculture research implementation which combines genetic and management methods in order to achieve desired results. Finally, the ongoing specification of carbon and ecosystem service payment instruments suggests their possible application as the means for solving the financial issue of the farmers in terms of costs incurred for diversification of activities and improvement of soil health – the issue of effectiveness of these instruments has not yet been widely studied in relation to small-scale farming.

6. Discussion

When examined as a whole, the literature reviewed here seems to present a coherent but somewhat unsubstantiated cause-effect story, stating that diversification results in a greater degree of functional and genetic redundancy of the cropping system; soil health management improves the biophysical resilience of the environment in which the cropping system operates; and resource use efficiency essentially reduces vulnerability due to late or wrongly timed supply of resources.
The agreement of results obtained in independent studies on cereal-legume net yield stability, cover-crop carbon sequestration, and conservation-agriculture nutrient retention indicates that the effects of any of the discussed pillars do exist and are not dependent on a limited number of groundbreaking studies. This relative reliability brings a lot of optimism for the farmers who want to find scientifically proven methods regarding any of the discussed pillars. Nevertheless, the discussion presented in Section 3.4 shows that when the subject is switched from individual methods to their combination, the relevant literature is much scarcer and weaker. Such discrepancy is of special importance as it is precisely the premise of the redesign paradigm that resilience is caused by the interaction of methods and not their combination. As a result, the lack of factorial field experiments can be regarded as a limitation rather than a research gap.
The contradictory results in scientific papers are not just inconvenient but also meaningful. For example, although it is true that diversification usually leads to lower yield deviation, some pieces of research claim that diversification might lead to high degree of vulnerability of poor crop combinations in terms of local moisture level or that the carbon sequestration effect of cover crops relies more on climatic and management duration rather than on diversity of cover crops. The outcomes from this analysis demonstrate that the advantages brought about by resilience when it comes to diversifying and improving soil health are conditional rather than universal. This aligns with the findings of several reviews that show that effective redesign of innovation requires context relevant solutions, rather than technical transfer.
Although years of agronomy research has resulted in a low nitrogen efficiency of 50-55%, it can also be noted that biophysical solutions are sufficiently known, meaning that there is no information deficiency preventing their implementation in agriculture. This can be proven to some extent by the three layers of information on this point, meaning that socio-economic and policy literature about the significance of problems related to technology adoption is confirmed by the evidence on the influence of obstacles hindering the use of these technologies.
In conclusion, the combination of precision and digital technologies with the emergence of nutrient and water management indicates that groundbreaking developments can happen as stated in Section 5.3, but actual evidence of such combinations with any long-term monitoring and improvement of soil health is scarce. Therefore, future research could focus on the integration of precision agriculture, restoration of soil health, and diversification rather than developing them separately.

7. Conclusion

The review highlights the results of various studies investigating the importance of the three pillars of climate resilience – crop diversification, soil health management, and input efficiency in their isolation and combination over the past decade. There is extensive evidence regarding the independent contributions of each of these three pillars to climate resilience; in particular, it has been established that crop diversification based on intercropping of various crops, especially cereals and legumes, has been successful in increasing yield stability; soil health practices such as the use of cover crops and conservation tillage have proved effective in the carbon storage capacity of soils; as well as water and fertilizer use efficiency technologies have proved to be effective in cutting GHG emissions. Nevertheless, the current state of research on synergistic potential of the three pillars has not been fully developed yet despite its theoretical attractiveness and the presence of a small number of studies offering promising results.
Within the framework of the literature review, recommendations were devised for researchers whose upcoming task will be to conduct long-term multi-location experiments dealing with the use and effectiveness of the three pillars simultaneously. An additional suggestion is to establish and verify a standardized multidimensional model for assessing resilience. Furthermore, geographical expansion of research into smallholder regions with a high vulnerability rate must be conducted since these areas have not been covered sufficiently in scientific literature. It is imperative that practitioners and public officials implement a monitoring system founded on indicators of soil health to develop climate-smart agricultural systems. Establishing the financial support system needed for interrelated diversification, soil health, and

precision inputs has been proposed for practitioners and public officials as well. Lastly, it is essential to focus on investing in market and institutional mechanisms such as credit, insurance, and ecosystem service payments that pose challenges for the use of current biophysical knowledge. Future studies should focus on developing digital decision-making tools along with agronomic redesign ideas in which precision technologies should be used for diversification and soil health management instead of an alternative approach.

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