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Environmental Research Communications

TOPICAL REVIEW

Building adaptive capacity of smallholder agriculture to climate change: evidence synthesis on learning outcomes

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Keywords: agriculture, development, knowledge management, scaling up, nexus

Supplementary material for this article is available online

OPEN ACCESS

RECEIVED
27 August 2021

REVISED
16 December 2021

ACCEPTED FOR PUBLICATION
20 December 2021

PUBLISHED
31 December 2021

Abstract

Increasing climate uncertainty coupled with more frequent extreme events poses a serious threat to the sustainability of smallholder communities dependent on agriculture for their livelihoods. Whilst there is extensive literature on adaptation options, there is a pressing need to understand what interventions have been successful in building smallholder's adaptive capacity, and how these have been transferred (nationally and internationally) through learning outcomes. The aim of this rapid evidence assessment was to assess the extent to which learning outcomes have supported initiatives to mainstream adaptation, focussing on three key areas, (i) scaling up climate sensitive adaptive interventions, (ii) the role of knowledge management to promote effective adaptive solutions, and (iii) human-ecosystem interactions in climate change adaptation. A protocol for the review was defined, from which 806 sources of evidence were retrieved. After screening for relevance using inclusion criteria, 91 were selected and the salient evidence extracted and synthesised. Access to knowledge remains one of the most important determinants of smallholders' decisions to respond to climate risk and a critical element in building adaptive capacity. The way knowledge is generated and exchanged is also directly relevant to securing effective scaling-up pathways. Learning platforms through participatory action research, farmer field schools and community-based initiatives were found to be particularly effective. However, knowledge based on local practices alone may be insufficient to prompt transformative action. Bridging local and external knowledge is critical because it widens the smallholders' knowledge base and encourages 'proactive' adaptation alongside more typical 'reactive' strategies. The contribution of evidence reviews to provide new insights to inform decision-making and investment in international development and the implications for advocating climate-sensitive policies at national and global levels are discussed.

Introduction

The socio-economic, environmental, and societal challenges facing 500 million smallholder farmers due to a changing global climate cannot be under-estimated. The impacts of extreme events including floods, droughts and heat waves will have profound implications on both food security and poverty reduction, especially for rural communities dependent on rainfed agriculture. As climate is a principal determinant of productivity, any changes will influence not only crop yields, but also all the agronomic aspects that are intrinsic to smallholder farming systems (Wheeler and von Braun 2013). Recent research suggests that a changing climate is expected to reduce yields of staple crops by up to 30% due to lower productivity and crop failure (Acevedo *et al* 2020). In sub-Saharan Africa (SSA) and parts of Asia smallholder farmers provide over three quarters (80%) of food consumed, and are responsible for managing extensive areas of land, yet they constitute the largest proportion of

the developing world's under-nourished people (Knox *et al* 2012). They also inhabit some of the most vulnerable and marginal landscapes, including hillsides, deserts and floodplains, where their assets are at risk from a variety of climate hazards. Many smallholders also lack secure land tenure and water rights further exacerbating their exposure and vulnerability to climate change (IFAD 2020).

In response to increased awareness of climate-related risks, there has been a sustained research and development focus on understanding impacts and adaptation responses. However, smallholder farmers in developing countries are also acutely vulnerable because of the ways in which climate change interacts with a raft of other so-called 'non-climatic' stressors (Mendelsohn 2001, Burnham and Ma 2016). Whilst extensive literature exists on understanding the vulnerability of smallholder farmer communities and how to build adaptive capacity, more recent academic debates and scrutiny of funding programmes have focussed on how to achieve sustainable agricultural development (Burnham and Ma 2016) whilst minimising environmental damage in the context of the UN Sustainable Development Goals (SDGs). To inform future investment in development programmes there will be a need to better understand how smallholder farmers perceive the risks of climate change, what adaptation strategies have historically been practiced (and why), and the factors that influence their decisions to adapt (Belay *et al* 2017). Crane *et al* (2011) reported that adaptation responses are often well embedded within communities, and that implementation measures should be appropriate and explicitly consider existing capacities and practices. Multi-sector collaboration will require coordinated action between farmer groups, local organisations, NGOs, the private sector, civil society and government agencies to formulate more climate-resilient pathways for action. This will require building the evidence base, increasing the effectiveness of local institutions, strengthening coherence between climate and agricultural policies and linking climate and agricultural financing (Lipper *et al* 2014).

Knowledge management (KM) often underpins the capacity of development agencies to deliver relevant projects in country, to offer expertise and technical assistance and to foster global south cooperation. It plays a pivotal role and can be a powerful agent for change, with KM, organizational learning and adaptive management increasingly recognized as important routes to more effective international development. In response, the International Fund for Agricultural Development (IFAD) which is an international financial institution and United Nations agency, developed a KM strategy which, through partnerships, aims to deliver better outcomes for poor rural communities whose livelihoods are dependent on agriculture, whilst contributing towards the 2030 Agenda for Sustainable Development, particularly SDG 1 (no poverty) and SDG 2 (zero hunger) (IFAD 2019). Their ambition is to share best available evidence and experiential knowledge to achieve higher quality operations, and greater visibility and influence in the global development community. However, successful KM is also contingent on strengthening knowledge networks and learning through scaling up. This is defined as expanding, adapting and supporting successful policies, programmes and knowledge so that they can leverage resources and partners to deliver improved results for a greater number of rural poor in a sustainable way. Interventions should not only enable rural communities to work their way out of poverty within time and resource constraints of a given project, but also to use the positive outcomes to inspire others and leverage policies, knowledge, social and political capital, and financial resources (from private, public and communities themselves) to scale up those results in a sustainable manner. Linked to both KM and scaling up activities is the need to ensure that human interventions do no harm to the environment and given that the coupling of human and natural systems is both strong and direct, adaptations to climate change should improve the resilience of both human and natural systems.

As part of a thematic evaluation, IFAD have assessed their performance across key areas including providing support for smallholders to manage climate risks, mainstreaming adaptation, advocating climate-sensitive policies at national and global levels, and scaling up climate-sensitive approaches. The aim of this rapid evidence review was to support that evaluation by focussing on what interventions have been successful in building smallholder's adaptive capacity, and how these have been effectively transferred as 'learning outcomes' specifically articulated along three axes, (i) scaling up climate adaptive interventions, (ii) effective knowledge management (KM) to promote climate adaptive solutions and practices, and (iii) the human-environment nexus in climate change adaptation. Definition of these learning outcomes and their relevance to building climate resilience is provided below. This review considered these determinants alongside the conditions and features of 'transformational' or more persistent adaptation pathways, usually framed in broader planned adaptation policies or interventions.

Methods

Our method followed the procedure for evidence reviews developed by the Collaboration for Environmental Evidence (CEE 2018) which sets out the logical approach for conducting the literature searches, data extraction and narrative synthesis. The approach was constrained by inclusion and exclusion criteria and an explicitly

Table 1. Defining the key PICO terms for the research question.

PICO	Description
Population	Food crop and livestock systems, excludes industrial crops (e.g. biofuel)
	Smallholder producers and subsistence farmers
	Peasant groups and farmers' organisations
	Rural farming communities, excludes urban/peri-urban agriculture
	Global South geographical focus
	Provide case study evidence from selected countries as appropriate
Intervention	Climate change, climate variability and climate extremes (intensity and frequency of droughts and floods)
	Production related interventions (not entire value-chain)
	Changes in landscape management or in natural resources management
	Reported behavioral changes in response to climate change risks
	Timescale from the baseline of 2020 to the 2050s
	Climate variables include changes in temperature and rainfall (annual and seasonal), extreme events (wind, cyclones), and flooding from causes other than rain such as ice and snow melt from glaciers
Comparator	Not relevant
Outcomes	Better adaptive capacity at household level and/or community level
	Improved resilience to climate related shocks
	Increased sustainability and diversity of agricultural production to support livelihoods and food security
	Positive environmental and socio-economic outcomes, such as improved ecosystem values and quality including biodiversity and water quality
	Behavioral changes linked to interventions as well as smallholders' attitude to risk, including adoption of climate smart agriculture
	Enhanced community resilience and/or collaboration
	Rural migration and off-farm adaptive solutions

defined research question, 'What interventions have been successful in building smallholders' adaptive capacity and responses to climate change and how have these been effectively transferred as learning outcomes in the three key dimensions of scaling up, knowledge management and ecosystem-human interactions?' This was then disaggregated into three subsidiary questions, relating to each learning outcome, namely (i) what recurrent determinants including pre-conditions, capacities, drivers (climate and environmental change) and triggers exist for securing effective scaling-up pathways? (ii) to what extent has knowledge management been explicitly considered in climate adaptation policies for smallholders and how is this effectively reflected in the promotion of climate adaptive solutions and practices? and (iii) to what extent have human and environmental interactions been explicitly considered in climate adaptation policies for smallholders as well as in intervention design, implementation and assessment? A brief description of the method is provided below, and further detail included in the supplementary information (available online at stacks.iop.org/ERC/3/122001/mmedia).

Since extensive scientific and grey literature exists on the impacts of climate change and adaptation options within agriculture, it was important to clearly define the boundaries of this review. Our specific focus was on the capacity and incentives of smallholder communities to adapt to climate change, and how learning outcomes are influenced by factors such as access to education, inequalities and gender, institutional governance and climate change awareness, rather than synthesising evidence on the raft of technology or infrastructural elements that are promoted as interventions in climate change adaptation. The review also considered the pre-conditions necessary for enabling effective climate change adaptation, and the capacity of smallholders to adapt, rather than the preferred changes in technology, management or agronomy that have arisen from adaptation intervention. This is an important distinction. Following CEE (2018) convention, the research question was broken down into four constituent PICO components, namely the population (P), interventions (I), comparators (C) and outcomes (O) (table 1). The term P refers to the unit of study, I relates to the proposed management regime, policy or environmental variable to which the population (P) is exposed, C relates to either a control with no intervention, alternative intervention or counterfactual scenario, and O relates to all relevant outcomes from the intervention (I) (CEE 2018). From this, unique keywords were defined and a listing of relevant bibliographic databases spanning the scientific literature (Web of Science, Scopus, ScienceDirect, Directory of Open Access journals, Ingenta Connect, Google Scholar.com) and other sources including organisational websites (e.g., IFAD, FAO, CGIAR, UNEP, Centre for Environmental Economics and Policy in Africa, Science and Development Network, Future Climate for Africa) (SI table 1).

As in all reviews, defining an appropriate search string that maps onto the PICO terms to adequately represent the main topics of interest is critical. A few search strings with and without 'wildcards' were trialled using the field 'title, abstract or author-specified keywords' in Scopus to assess the number of 'hits' each search returned. The search string 'smallholder, AND agric*, AND climat* AND change, AND adapt*' was selected

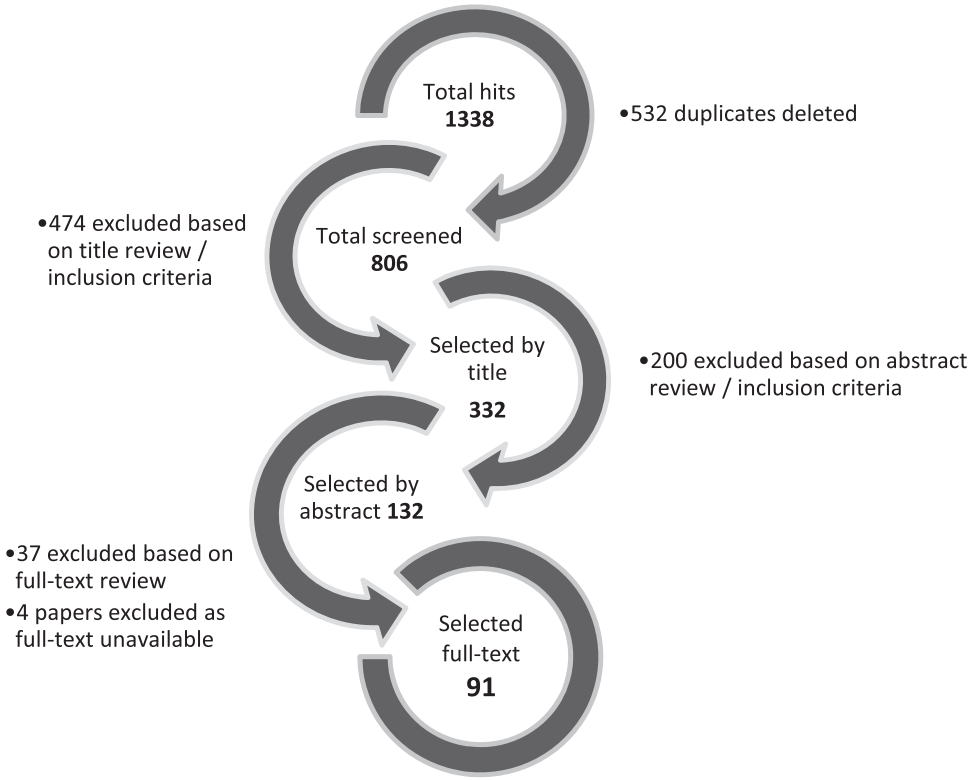

Figure 1. Schematic representation of the rapid evidence review process.

since it provided a good balance between relevant key terms and returned a high but manageable number of 'hits' from the initial title screening. Including terms specifically related to one or more of the three learning outcomes in the search string restricted the search results. Other search filters were applied for language (English) and the starting publication year (2004) which corresponded to when IFAD started to explicitly address climate adaptation as an organizational priority. Academic sources were sampled first, to avoid later duplication from less specialised databases. For the websites, the search string would vary slightly depending on the rules for use of wildcards, Boolean operators and search fields, but the key terms were always included. The number of 'hits' returned from each source is given in SI table 2. The searches returned 1338 results which were exported to MS Excel. Following removal of duplicates, the final cleaned dataset included 806 publications, each listed by author, title, publication year, source, abstract and affiliated institution.

The database was initially screened based on title only, and a second filter then applied based on the abstract. The screenings were undertaken independently by two researchers and then compared for consistency. The PICO terms (table 1) and inclusion criteria (SI table 3) were used to inform each screening stage. Given that the types of studies included in this review did not include those that conducted controlled experiments, the C component was not relevant. Regarding the types of intervention, and in order to avoid characterising every activity as supporting climate change adaptation, interventions were screened on the basis of two criteria, namely (i) the presence of a climate risk expressed either as a projected change in future climate, increased climate variability or climate extreme (intensity and frequency of droughts and floods), and (ii) the action would plausibly enhance smallholders and ecosystem capacity to address that risk. A range of data sources were screened including peer reviewed journal articles, conference proceedings, research reports and book chapters, and primary and secondary sources including meta-analyses, systematic reviews and corporate impact evaluations from international organisations such as IFAD, the World Bank and FAO. Figure 1 summarises each step in the review. After screening the titles and abstracts, 132 of 806 resources were selected for full-text reading with 128 papers and articles successfully retrieved. Of these, 91 were selected for the final review and 37 rejected, either because they did not meet the inclusion criteria, were not relevant to any of the learning outcomes, were redundant or of poor methodological quality. Each publication was reviewed, and key information extracted and incorporated into a database in MS Excel. This information included key attribute data relating to where and when the research was undertaken, the focus of the research, and its relevance to a particular learning outcome. This data was then used to generate summary statistics on the evidence. More detailed thematic information was also extracted on research outcomes that were relevant to the specific questions that had been formulated for the evidence review and synthesised using a narrative approach. This is more suited to studies of this nature where

Table 2. Summary of key findings from the evidence review for each learning theme.

Scaling up adaptation in smallholder agriculture
Planned adaptation should build upon complementary strategies that address both the underlying determinants of adaptive choices (access to knowledge and information) and the enabling factors (such as productive assets, human capital and institutional support)
Equitable and inclusive adaptive patterns depend on different groups' adaptive capacities and possibilities; fully considering the barriers to adaptation relating to wealth, gender and other socio-economic dynamics is essential to align planning to different impact scenarios
Sustained adaptation and scaling up rely on some recurrent factors: (i) integrated, multi-sectoral interventions, (ii) participatory approaches to planning, implementation, and dissemination, and (iii) knowledge exchange and co-creation of knowledge
Partnerships for knowledge management and capacity building
Access to knowledge is both a determinant and an enabling factor of smallholders' willingness and capacity to adapt; external knowledge and information need to be easily available (supplied) and accessible (farmers should be able to understand it and use it effectively)
Bridging local and external knowledge is critical as it widens farmers' knowledge (based on lessons learnt from the past) to include more forward-looking considerations; inducing 'proactive' adaptation alongside 'reactive' strategies helps prompt more transformative action
Both formal groups and informal collective action can foster synergies for adaptive capacity building through social learning. Learning platforms based on inclusive participation effectively support adaptation by linking science, policy and practice in the bid to tackle multiple challenges
Human and ecosystem nexus interactions
Farmers' social structures, and especially networks structured around knowledgeable actors, or sustainability champions can help achieve desired environmental outcomes. Social capital in the form of collective action is also extremely important
A trans-disciplinary approach across the economic, social, and environmental domains, with more explicit integration of disciplines and practices, is needed to solve trade-offs (e.g. farm productivity and ecosystem conservation) and barriers to longer-term adaptation
Adaptive actions undertaken at individual and community levels should find space and consistency in a higher-level framework that provides enabling conditions such as institutional support (e.g. rights to land) and economic incentives or payments for ecosystem services

the subject content and range of potential outcomes can be broad. One advantage of the narrative approach is the potential to identify gaps in knowledge and areas for targeting future development programmes. A list of the 91 references used in the review is given in the SI.

Results and discussion

This section summarises the nature and composition of the evidence gathered and provides a narrative synthesis in relation to the three learning themes. To support interpretation, an overview of the key findings is given in table 2.

Nature and composition of evidence

In addition to synthesising the scientific findings from the literature it is also important to consider how and where that evidence has developed over time. During the review process, key information was extracted to facilitate the production of summary statistics. SI figure 1 shows the temporal trend in relevant publications, and the rising and recent interest in the topic. As expected, most evidence (73%) was obtained from the peer reviewed literature, followed by technical project reports (18%) and book chapters (7%). There was also a noticeable rapid increase in the number of peer reviewed papers from 2016. SI table 4 shows there was a good balance between quantitative and qualitative based studies across all publication types. Regarding the quality assessment of the literature, in other disciplines, a 'hierarchy of research methodologies' is often used to score data in terms of its scientific rigour. However, this approach would not work in this study because the environmental context of each study provided too much 'internal' variability.

Regarding specific research topics, most of the evidence dealing with smallholder adaptation had a focus on farm management (29), followed by those on knowledge management (22) and governance and institutions (11). Only seven studies investigated specific issues linked to natural resources management, although some of the resources with a broader or multifaceted research scope classified 'other' (22) also dealt with environmental and natural resources issues (SI table 5). In terms of geographical focus, the literature included evidence from many different countries; however, sub-Saharan Africa was the most represented region (notably southern and East Africa), accounting for over half (53%) of all papers, followed by Asia and the Pacific (23%) and Latin America and the Caribbean (9%). A small proportion (15%) had a global or multi-country scope, but always with a focus on the Global South (figure 2). A fundamental question for the review was to assess the extent to which the available evidence would contribute to our understanding of the three learning outcomes. Most of the sources provided insights for 'scaling up', either directly (28%) or indirectly by addressing the determinants and

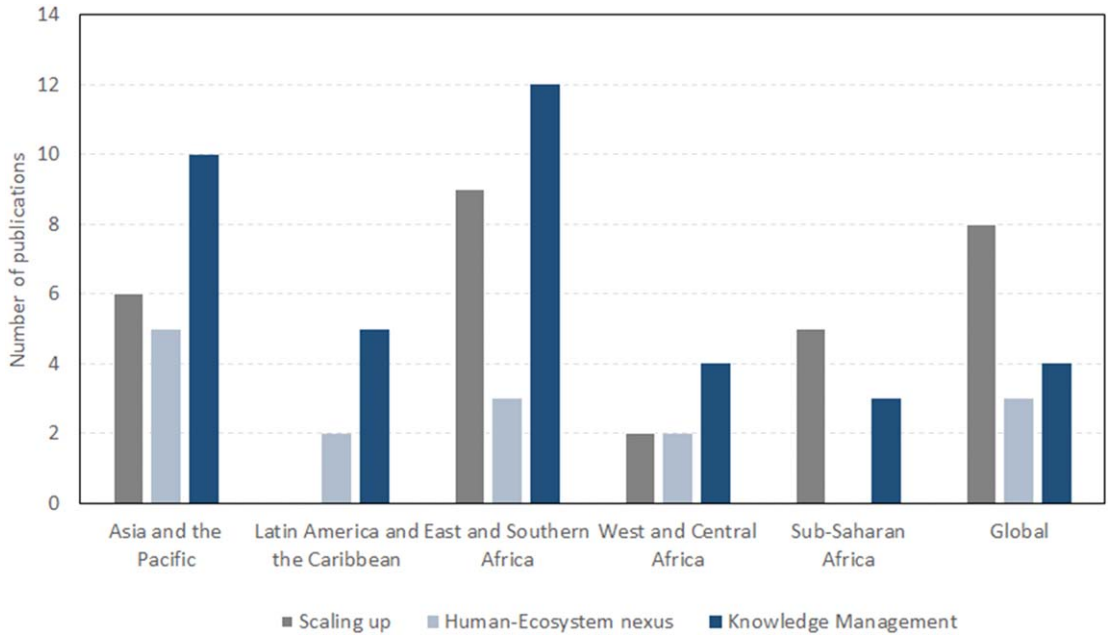

Figure 2. Reported number of publications, by region and defined learning outcome. SSA refers to an amalgamation of each reported region in Africa; Global refers to Global South.

barriers to the adoption of adaptive practices and behaviours by smallholders (24%). About a third (35%) provided insights in relation to knowledge management, whereas only 14% were relevant to human and ecosystem interactions.

Scaling up adaptation in smallholder agriculture

There is extensive empirical literature investigating the underlying conditions and enabling factors that determine the uptake of autonomous adaptation measures. These determinants were evaluated alongside the conditions and features of 'transformational' or more persistent adaptation pathways, usually framed in broader planned adaptation policies or interventions. Equity and inclusion considerations are also important determinants in the social and economic sustainability of smallholder adaptation. Access to knowledge is one of the most important determinants of smallholders' decisions to adopt climate change responses. It is also a critical element in building adaptive capacity. The way knowledge about the impacts of climate change and its variability—and of potential responses—is produced, transferred and exchanged is thus extremely relevant to securing scaling-up pathways.

Scaling up a process or initiative does not only imply bringing it to scale (to more people, and/or across a larger area) or adapting it to similar conditions in different locations (horizontal scaling up). It can also mean moving a project forward into a more developed, complex phase, possibly involving new components, configurations and stakeholders (diagonal scaling up). There can also be vertical scaling up which consists of mainstreaming a certain approach into policy, thus leveraging and catalysing policy and institutional change (Neufeldt *et al* 2015). This review thus explicitly considered the recurrent determinants including pre-conditions, capacities, drivers and triggers needed to secure effective scaling-up pathways. Two types of publication were relevant, namely (i) articles in the academic literature which explored the determinants and barriers to the adoption of practices and behaviours, and (ii) fewer articles and research papers which offered more articulated discussions on the long-term or transformational achievements of adaptation strategies. The former were quantitative analyses that considered a given population at one point in time to investigate possible correlations independent variables (gender, age, assets, social relations) and one or more dependent variables linked to the adoption of one or more changes in practice and/or behaviour. These studies were useful in tracing the underlying conditions and enabling factors that support farmers' decisions to respond to a particular risk—a critical step in planning adaptation. However, they often didn't provide deeper insights or understanding of what characterises sustainable and inclusive adaptation patterns over the longer-term.

Scaling up may also refer to 'social' scaling up (increasing social inclusiveness) and conceptual scaling up in terms of moving beyond participation to embedding empowerment in the entire development process (Binswanger-Mkhize *et al* 2009). A few studies addressed this broader definition by adopting a more dynamic, longer-term, and broader perspective in describing adaptation patterns. Some were case studies that investigated

a specific practice or set of practices adopted in response to climate stressors (usually in combination with other sources of vulnerability) and then explored the causes behind their use and/or wider uptake over time. Of relevance was a review by Vermeulen *et al* (2018) that set out the concept of 'transformational' adaptation across 23 case studies.

Three key messages on scaling up emerged from the evidence. Firstly, planned adaptation should rely on complementarity and integration of strategies so that the underlying determinants of adoption, such as access to knowledge and information, exist alongside enabling factors, such as the endowment of productive assets, human capital (education and skills) and institutional support (for example, existence of farmer groups and collective action). Secondly, understanding the existing socio-economic conditions is essential to align planning to the expected impacts for different smallholder categories and to meet different groups' adaptive capacities. The barriers to adaptation relating to wealth and gender as well as to the dynamics of power and decision-making need to be considered to ensure equitable and inclusive development patterns. Finally, whilst it is not possible to identify common solutions that are applicable across all contexts, there are some recurrent features of sustained adaptation and scaling up. These include (i) integrated, multi-sectoral character of interventions, (ii) participatory approaches to planning, implementation, and dissemination, and (iii) fostering knowledge exchange and co-creation of knowledge. Institutional and social capital aspects were also important.

Partnerships for knowledge management and capacity building

The evidence on knowledge management focused on the relative importance of either local knowledge and/or external, scientific knowledge on patterns of smallholder adaptation and how potential tensions stemming from inequitable 'politics of knowledge' can be solved. Several publications suggested that social learning, facilitated by one or more 'knowledge brokers', was a viable and effective solution. Learning platforms for multiple stakeholder interactions, including farmer field schools and similar practical demonstration training and other participatory communication solutions were also reviewed.

The way knowledge and information are produced, shared and transferred exerts a strong influence on individual as well as community adaptation patterns. Awareness of risks and cognisance of potential responses are important determinants of smallholders' willingness to pursue adaptation strategies. In addition, knowledge in the form of education, technical training, and skills transfer are the enabling factors that facilitate smallholders to adapt, i.e., it is a critical element of adaptive capacity building. For example, in 2010 a participatory rural appraisal exercise conducted by IFPRI in Kenya confirmed that farmers were aware of this link. Both men and women who were involved mentioned 'capacity building' defined as training, extension and information but also as support to formal and informal groups, as the most important resource needed for adaptation (Roncoli *et al* 2010). Similarly, a study in South Africa revealed that while media sources provide smallholders with information on climate change, such information on its own doesn't allow them to cope with change (Thinda *et al* 2020). Farmers identified the most critical adaptation constraint being a lack of access to extension and other advisory services that help them mediate and assimilate the relevant information. The lack of information on climate change coupled with a knowledge gap in coping strategies were also identified as critical constraints in Nigeria, Ghana and Pakistan (Popoola *et al* 2020).

Building adaptive capacity doesn't rely solely on external, scientific knowledge. Knowledge embedded in farmers' experience and tradition is also critically important to raise their awareness of climate risks and to select appropriate responses. The evidence confirmed that indigenous knowledge is an important source of inspiration for locally suitable practices and behaviours. Autonomous adaptation often occurs based on farmers' perception of climate change and variability. Local knowledge is fundamentally important for understanding and dealing with climate change, as farmers take measures primarily based on their perception. However, autonomous adaptations may be limited in scope and may be not effective in the long run (and even lead to maladaptation) as they respond to experienced threats and not to ongoing or projected changes (Akinyemi 2017, Makate 2019). Also, knowledge based on local practices may not be sufficient to prompt more transformative actions that account for inter-generational equity (Derbile *et al* 2016), or to embark into risky activities such as changing crop types and/or investing in irrigation (Etana *et al* 2020).

Bridging local and external knowledge is therefore critical as it broadens the farmers' knowledge base to include more forward-looking considerations (or, to induce proactive adaptation alongside reactive strategies, which may not always be sustainable in the long-term). The supply of scientific or external information, *per se*, doesn't imply that it is passed on, understood, and accepted; it depends on how it is communicated and if it matches smallholders' needs. Information and knowledge barriers are strongly linked with cognitive barriers (in fact, information is mediated and understood by each person's education and culture). For instance, different initial interpretations due to farmers having a shorter timeframe of perception compared to scientists, may lead to misunderstanding and persistent mistrust (Shackleton 2015, Etana *et al* 2020). To support long-term,

sustainable adaptation, both local and external knowledge should be embraced within innovation processes (Shackleton 2015, Makate 2019).

Three key messages on knowledge management emerged from the evidence. Firstly, access to knowledge influences awareness of risks and cognisance of potential responses and is thus an important determinant of smallholders' willingness to pursue adaptation strategies. Knowledge in the form of education, technical training and skills transfer are also critical enabling factors for up taking adaptation in practice; when knowledge and information are transferred along more 'structured', one-way channels, communication solutions need to be both easily available (supplied) and accessible (farmers should be able to receive it, understand it and use it effectively). Secondly, local knowledge is fundamentally important for understanding and dealing with climate change. However, autonomous adaptations may be limited in scope and may not be effective in the long run. Knowledge based on local practices may not be sufficient to prompt more transformative action. Bridging local and external knowledge is thus critical because it widens the farmers' knowledge base to include more forward-looking considerations or, to induce 'proactive' adaptation alongside 'reactive' strategies. Finally, social learning (deep understanding and assimilation of concepts through social interaction) was reported to be an effective mechanism to link science, policy and practice to tackle multiple and related challenges of agricultural development, food security and climate change adaptation. Both formal groups and informal collective action can foster synergies for capacity building through social learning, but to ensure inclusion, social differentiation must be considered. Learning platforms based on participatory action research that bring together different actors have been shown to be particularly effective in supporting adaptation.

Human and ecosystem nexus interactions

Whilst the evidence on scaling up and knowledge management often proposed a multi-sector approach and stressed the importance environmental considerations to secure equitable and sustainable adaptation, literature on the interactions between humans and ecosystems, or that using an environmental lens to discuss adaptation in smallholder agriculture, was sparse. This lack of evidence is nonetheless relevant since it highlights an important gap in knowledge. This nexus 'learning outcome' focuses on the extent to which human and environmental interactions have been explicitly considered in climate adaptation policies for smallholders as well as in intervention design, implementation and assessment. However, some issues did emerge, including the importance of farmers' social networks to adopt environmentally sustainable practices, the opportunities linked to ecosystem-based adaptation and the relevance and importance of adopting a 'landscape' approach. Smallholder farming is tightly coupled to local ecosystems and ecosystem goods and services (EGS) are the backbone for farmers livelihoods. Agriculturally based economies depend on healthy soils, water, forests and farm based EGS, including for example, fodder for animal feed or dung and fuel wood for energy supply. At the landscape level, forests protect farmland from erosion, protect the biodiversity of natural predators and contribute to watershed management securing water for productive and other uses (Adhikari *et al* 2018). To varying extents, all smallholders rely on these interactions between their farming activities with those of their surrounding environment. Common natural pool resources such as forests and wetlands also provide households with alternative or complementary sources of livelihoods and income and, more generally, a healthy and productive landscape encourages households to remain in rural areas, slowing down outward migration from the countryside whilst increasing income opportunities and sustaining local adaptation (FAO 2014, Arouna and Akpa 2019).

The interactions between small-scale farming and the environment may also have negative connotations. Farmers are exposed to natural disasters and weather extremes. On the other hand, even if smallholder agriculture does not contribute to water and air pollution as much as large-scale farm and livestock production, anthropogenic activities such as grazing, intensive farming, encroachment, and deforestation can severely undermine the natural resource base at local level and ultimately smallholders' livelihoods. In Zimbabwe, for instance, declining and erratic agricultural yields pose increasing pressure on the use of EGS from common natural resources pools (CNRP) such as wetlands and woodlands. These play an important role in sustaining livestock, agriculture (especially irrigation) and crop-livestock integration but also as a source of food security (wild fruits, vegetables) as well as alternative livelihoods and income (wood, crafts, medicines, especially for vulnerable households).

The progressive increase in these alternative uses (and increasing competition over their use) places these areas at risk, exacerbating the impacts of climate change and climate variability. Two CNRP pressures are emerging as a direct consequence of climate change, firstly, the areas of wetlands and woodlands are reducing, and secondly, the impacts of climate change are coming indirectly through the human system, with higher extraction rates and land use changes to expand cultivated and grazing areas (Chagumaira *et al* 2015). Despite these important interactions, the review identified only a few studies that explicitly investigated the links between smallholder agriculture and the ecosystem within the context of climate change adaptation. For

example, El Chami *et al* (2020) explored the literature dealing with the contribution of sustainable agriculture to resilient agro-systems in the context of a changing climate. Although it didn't have a specific focus on human-environment nexus or NRM, it confirmed the limited relationships that exist between disciplines and the gaps in the literature. It showed that different management aspects were often studied separately, meaning that the literature has not considered sustainable agriculture as an entity but merely some practices and technologies that form part of sustainable agriculture, mainly through the improvement of system biodiversity and ecosystem services (El Chami *et al* 2020).

While the results from this review are of course influenced by the search strings and inclusion criteria, the paucity of sources on this topic also reflects a reality where policymaking and planning in agriculture, environment and climate change still occur in silos with limited exchange between different disciplines and practices. This is a key concern and should be recognised as a strategic development priority. Drawing on our evidence, three main areas of intervention can be identified that support a stronger integration of the nexus between human and ecological systems into adaptation planning, implementation, and assessment. Firstly, several studies call for a reframing smallholder farming and, more generally, agriculture, as an integrated system alongside natural resource management, energy, and climate change through a more holistic approach. Secondly, some evidence exists on the benefits as well as challenges of ecosystem-based adaptation to pursue more equitable and transformational adaptive strategies. Finally, social capital in the form of social networks and collective action are critical to achieving environmental outcomes; community-based adaptation must be supported, and adaptation should be addressed across different levels from the individual through the community up to the landscape scale. Farming has important inter-linked social, ecological, and technical systems which need to be recognised.

The constraints and challenges in the agricultural sector should be addressed holistically, considering food and energy production, environmental protection, and climate, water and waste management being interconnected and mutually dependent (Reid *et al* 2013). One key element to such a holistic and circular economy approach is the local dimension. In adaptation planning, this implies keeping local perspectives central both in the search for technological solutions and in policy agreements. For this to happen, it may be necessary to challenge the power imbalances and decision-making rules to ensure local people and organisations' needs (and possible solutions) are acknowledged by policymakers. Knowledge management and how information is produced, transferred, and used was highlighted as a key component and one which could shift current mindsets in policy, practice and research (Reid *et al* 2013).

The key messages on human-ecosystem nexus interactions that emerged from this review are summarised below. Firstly, there were few studies that explicitly investigated the links between smallholder agriculture and the ecosystem within the context of climate adaptation. A paucity of sources on this topic reflects the fact that policies in agriculture, environment and climate change still tend to be formulated in isolation with limited exchange between different disciplines and practices. Secondly, a transdisciplinary approach across the economic, social, and environmental domains with explicit integration of potential interventions at multiple levels, is needed. Farmers' social structures, and especially networks based around knowledgeable actors, or sustainability champions can often help achieve desired environmental outcomes at the local scale, and social capital in the form of collective action is also extremely important. Finally, to be transformative, actions undertaken at individual and community levels should find space and consistency in a higher-level framework that ultimately solves the trade-offs and barriers for longer-term, sustainable results. Beyond providing the enabling policy and legal environment (for example, land tenure, access rights for natural resources), external institutions (such as governmental and international organisations) can help integrate the three levels of intervention—household, community, and landscape—and, importantly, provide the right economic incentives to compensate smallholders for investments that don't deliver immediate returns, such as agroforestry.

Methodological limitations

Evidence reviews are generally best applied to studies where there is good primary data. However, this review was limited to assessing outputs from a wide range of climate change adaptation studies, all of which inevitably contained 'effect modifiers'. These included, for example, gender, levels of education and access to educational support, land tenure/access to land and other natural resources, or landscapes. There was also much heterogeneity in the resources included in this review: many studies were context-specific (village or landscape level) and their methodologies varied greatly. The heterogeneity was also due to the overall review question being disaggregated to cover the three inter-linked, yet quite different domains. This made it difficult to compare and aggregate results. To minimise bias, care was exercised in interpreting studies reporting climate change adaptation interventions across similar agricultural systems but conducted using different methodologies, as there was no single discriminator that could be used to determine which model/approach was best.

Potential limitations in comparing evidence stem from the variety and often inconsistent use of definitions. Burnham and Ma (2016) explored how literature has documented and conceptualised autonomous adaptation and reported a lack of conceptual clarity: multiple definitions of adaptation were used, and it was not always specified whether climate change referred to long-term variations, seasonal variations, or a combination. Many studies also differentiated conceptually between coping and adapting, and many included very different concepts under the 'adaptation' term with no clear definition of the temporal dimensions of both responses and stressors (Burnham and Ma 2016).

Policy implications for smallholder adaptation to climate change

The review identified some important pitfalls for policy making in systematically transferring lessons into practice to support transformational adaptation in agriculture. Some barriers were financial, technical and/or of organisational nature, but others were more fundamental and will require a marked shift in how different stakeholders decision-making processes are framed and implemented. For adaptation pathways to be transformative and inclusive, the current policy making process must undergo change, including taking on a more holistic approach to address vulnerability as stemming from a complex web of causes, of which climate change is only one aspect. High-level policies should also build upon local experiential knowledge and priorities. However, there was a disconnection with insufficient coordination between policy, research and practice whereby smallholders' needs, and preferences are increasingly shaped by external actors. Mainstreaming successful local adaptation into large-scale planning requires participation, active stakeholder engagement, and devolution of rights and responsibilities. Methodological improvements are also needed to assess and evaluate adaptation outcomes as monitoring and evaluation is at the core of understanding and scaling up what works in practice. Stakeholder platforms can also provide a powerful tool alongside other analytical methods to encourage mutual learning, communication, and governance. Participatory research and experimentation are also needed to better understand and manage the trade-offs amongst competing objectives, and to better evaluate the social costs and benefits in the calculation of payment for ecosystem services and other economic incentives for farmers.

Finally, although our understanding of climate change adaption and the priorities for action in development programmes have become clearer in recent years, incorporating more explicit recognition of youth and gender, marginalised communities, and the value of local knowledge, the consensus on actions needed remains contested. This is because understanding the elements and interventions within smallholder agriculture and its need to adapt to climate change are non-linear, complex and interdependent; the implementation of interventions through investment programmes requires effective partnerships and concerted cooperation across multiple organizations and scales and hence the inherent difficulty in identifying clear 'lines of sight' between planned interventions and desired impacts (Tomic *et al* 2019).

Conclusions

This study set out to identify interventions that have been widely promoted to build smallholders' adaptive capacity to climate change, and how these have then been effectively transferred as 'learning outcomes' at a range of regional, national and global scales. The analysis provides the first systematic review of published scientific and grey literature and valuable evidence to support more informed decision-making and programmatic investment by agencies involved in international agricultural development. There are clear opportunities for robust evidence to usefully contribute to ongoing policy dialogue and scientific debate.

Successful scaling up is shown to be characterised by interventions that adopt genuinely integrated, multi-sectoral and participatory approaches to planning, implementation, and dissemination, and foster co-creation of knowledge. Access to knowledge remains one of the most important determinants of smallholders' decisions to respond to climate risk and a critical element in building adaptive capacity. The way knowledge on climate change is generated and exchanged is thus extremely relevant to securing effective scaling-up pathways.

The review also confirmed that learning platforms based on participatory action research, farmer field schools and other community-based initiatives are particularly effective. Whilst local knowledge is fundamentally important for understanding and dealing with climate change, the preferred autonomous adaptations may be limited in scope and not effective in the long run, potentially leading to maladaptation. Knowledge based on local practices alone may also be insufficient to prompt more transformative action. Bridging both local and external knowledge is thus critical because it widens the smallholders' knowledge base and encourages 'proactive' adaptation alongside more typical 'reactive' strategies. Development programmes should therefore incorporate robust strategies for knowledge management at the outset in the design phase, rather than viewing knowledge management as part of communication and outreach in the latter stages of project implementation.

Finally, the study has reaffirmed a rather concerned view that the links, opportunities and trade-offs between smallholder agricultural development and ecosystem preservation within the context of climate change adaptation remain largely ignored. Policies for agricultural transformation, environmental protection and climate change adaptation are unfortunately still lacking a coherent and integrated perspective. To achieve transformative adaptation, actions undertaken at varying scales from individual smallholder to community levels will need to find common space and consistency within higher-level integrated frameworks to address the necessary trade-offs and barriers to sustainable development. Strong institutional governance that provides both the enabling policy and legal environment and economic incentives to compensate smallholders for climate change adaptation investments that deliver against multiple agronomic and environmental benefits needs to become a key priority.

Acknowledgments

This research was funded by the International Fund for Agriculture (IFAD) as part of a broader thematic evaluation of their global development programme on smallholder adaptation to climate change. The authors acknowledge colleagues from the evaluation team who provided valuable critique including Nurul Alam, James Gasana, Margarita Borzelli Gonzalez, Christian Hergarten, Prashanth Kotturi, Susanne Leloup, Carsten Schwensen and Horst Weyerhaeuser. Data referred to in this article are available from doi:10.17862/cranfield.rd.15090246.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.17862/cranfield.rd.15090246.v1.

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