Stakeholder perceptions on potential of irrigation to adapt to climate change in mixed farming systems of the Mid-Hills of Nepal: A Fuzzy Cognitive Mapping study with farmers, extension and researchers– Summary Report

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Published by CIMMYT

November 2024

WU Course Code: FSE80436

WU-supervisors: Jeroen Groot, Yifan Wang

Status: Summary Final Thesis Report

Author: Lisa Vissers / Jeroen Groot

Place of publication:

Wageningen University & Research
Droevendaalsesteeg 4, 6708 PB Wageningen

The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

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1 Country background and research objective

A prevalent challenge in the agricultural development sector is the alignment of perceptions among different stakeholder types involved in sustainable intensification. Due to differing visions, or a lack of communication thereof, new practices can fail to be adopted (Christen et al., 2015). Perceptions originate from the belief systems of stakeholders, so called ‘mental models’. Therefore, to successfully implement new sets of practices, it is important to understand stakeholders’ belief systems, in particular those of researchers, extension agents and farmers. In South Asia, agronomic interventions developed through research-extension systems that generally focus on new technologies but overlook farmers’ knowledge and perspectives and can result in context insensitive interventions (Aravindakshan et al., 2021).

To identify locally appropriate target indicators, it is crucial to explore farmers’ conceptualizations of farm system components, dynamics and performance. Gaining an understanding of the perceived functioning of the agroecosystem will give insight into the associated decision-making in terms of farm management (Vanwindekens et al., 2013). Moreover, comparing these perceptions with other stakeholder types, such as researchers or policy makers, plays an important role in effective adoption, so that differences can be identified and integrated in implementation strategies (Halbrendt et al., 2012).

Farmers operating rainfed farms in the mid-hills of Nepal are confronted with significant challenges. The region's climate, characterized by concentrated monsoon rainfall and prolonged dry periods, makes year-round agricultural production impossible. Climate change is expected to further exacerbate the irregular temporal distribution of water (CIAT, 2017). The unpredictable water supply threatens the livelihoods of these farmers.

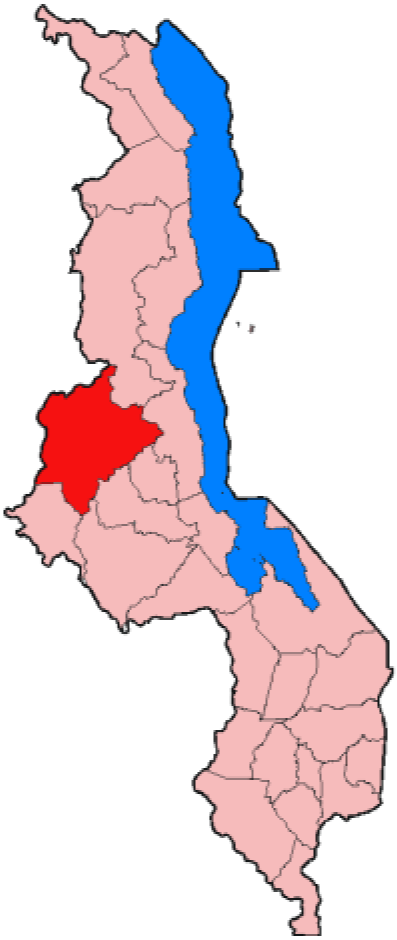
Small-scale and micro irrigation offers promising solutions to stabilize water availability and mitigate the adverse effects of climate-induced variability on agriculture. However, the successful implementation of irrigation systems in these areas with challenging topography face not only challenges in infrastructure design; it also requires an understanding of the perceptions of the different stakeholders involved. These stakeholders include the farmers who could use the irrigation systems, the local government responsible for supporting agricultural initiatives, and researchers who provide additional knowledge.

Currently, it is unknown to what extent perceptions of these stakeholders align on the potential benefits of irrigation in terms of enhancing food security and increasing cash income with the prospect of climate change. The main objective of this research is to assess and compare the perceptions on the potential mitigative properties of irrigation on cash income and food security in times of climate change among different stakeholder types in Khotang district, Nepal. The specific objectives for this research are:

1. To gain insight into stakeholders' perceptions of the current rainfed farming system components, dynamics and performance.
2. To understand how livelihood outcomes (i.e. cash income and food security) change in response to scenarios of climate change and irrigation intervention according to the perceptions expressed in the FCMs.
3. To identify the discrepancies and communalities in the perceptions of the different stakeholder types.

2 Methodology

2.1 Study area



The case study of Halesi Tuwachung Municipality, Khotang district is situated in the eastern mid-hills of Nepal, with altitudes ranging from 300-4000 meters above sea level (Topographic Map, n.d.). Khotang is characterized by subsistence terrace farming with farm sizes ranging from 0.05-10 hectares. The area has three cropping seasons: the main or monsoon season (July-October), winter (November-February) and summer (March-June) (Shrestha, 2024). Agriculture traditionally consists of mixed farming systems integrating crops and livestock (CIAT et al., 2017). Maize and millet are the primary crops, which are relay cropped. Vegetables are produced around the homestead for home consumption. The surplus is sold and there are some attempts at commercial production of fruits. Livestock generally consists of cows, buffalos, goats, pigs, and chickens that feed on cereal straw, grass, maize, or wheat flour. Fodder is also collected in forests or, in the case of pigs, bought (Shrestha 2024). However, due to fodder and water shortages, livestock production is low. The limited manure production and poor manure management practices negatively impact soil fertility and crop yields, creating a vicious cycle of low agricultural production. Moreover, few farmers have access to irrigation, so most are dependent on rainfed crops, leaving agricultural land fallow in pre- and post-monsoon seasons (Adhikari & Shrestha, 2023). Monsoon crop production does not cover the year-round food demand of the population, resulting in food insecurity (Koirala et al., 2022).

Figure 1. Khotang district, Nepal indicated in red. (Copyright: 2021 Nepali Times).

2.2 Modelling approach

A Fuzzy Cognitive Map (FCM) is semi-qualitative tool to represent a belief system regarding a certain domain (Kok, 2009). Cognitive Mapping was first introduced by Axelrod (1976) to represent social scientific knowledge, which was extended by Kosko (1986) with the notion of 'fuzziness' (Vanwindekens et al., 2013). The 'fuzziness' refers to the uncertainty or vagueness of the logic in cognitive maps (Kosko, 1986).

FCMs consist of system components, or concepts, and interrelations between these concepts, so called edges. Concepts visualize system drivers and constraints, and edges represent perceived causal relationships between concepts. Edges are assigned weights, a value between -1 and +1, indicating a respective negative and positive relationship between concepts. (In)direct linear feedback, or reinforcing effects, can also be included in FCMs and demonstrate how this results in non-linear system changes (Kok, 2009). A drawback of the method, however, is the different timescales at which the processes that are represented by concepts operate. For example, when evaluating concepts that influence crop water availability, rainfall has a long-term influence, whereas irrigation exerts a more immediate, daily influence. Yet, in the analysis of the model, both factors are treated equally. To avoid misleading conclusions, this limitation should be accounted for when interpreting the output (Barbrook-Johnson & Penn, 2022; Kok, 2009).

The data was collected in two consequent group modelling sessions per stakeholder type, resulting in six sessions in total. The format of group modelling sessions was selected to emphasize the importance of participatory research, as well as chances for interaction and collaborative learning (Knox et al., 2024). The objective of the group modelling sessions was twofold: firstly, to get an overview of how the stakeholders conceptualize the current rainfed farming system. Secondly, to assess how this perceived system responds to events of climate change and an irrigation intervention.

The second group modelling sessions started with a validation of the baseline model created in the first session. The participants were asked if there were concepts and/ or edges missing, or concepts/ edges they disagreed with. After the remarks were adjusted, two scenarios were explored with the participants. Firstly, the participants were asked which events/ processes are induced by climate change. Next, these were connected to the concepts of the previously established baseline model. In the last part of the session, the scenario of an irrigation intervention was introduced, after which the stakeholders were asked to relate this concept to the components of the rainfed farming system.

Identifying (partially) overlapping and unique concepts between the FCMs formed the starting point to investigate the discrepancies and communalities in the perceptions of the different stakeholder types regarding the current rainfed farming system (Yoon & Jetter 2016). Next, graph theory served as a tool to analyze the structure of FCMs, and for inter-stakeholder comparisons (Özesmi & Özesmi 2004). The structures of the FCMs were assessed based on network metrics.

The physical Fuzzy Cognitive Maps created with the stakeholders during the group modelling sessions were translated into digital Fuzzy Cognitive Maps with software tool FuzzyDANCES.

3 Results

3.1 Baseline FCMs

The FCMs created by farmers are shown in Figure 2.

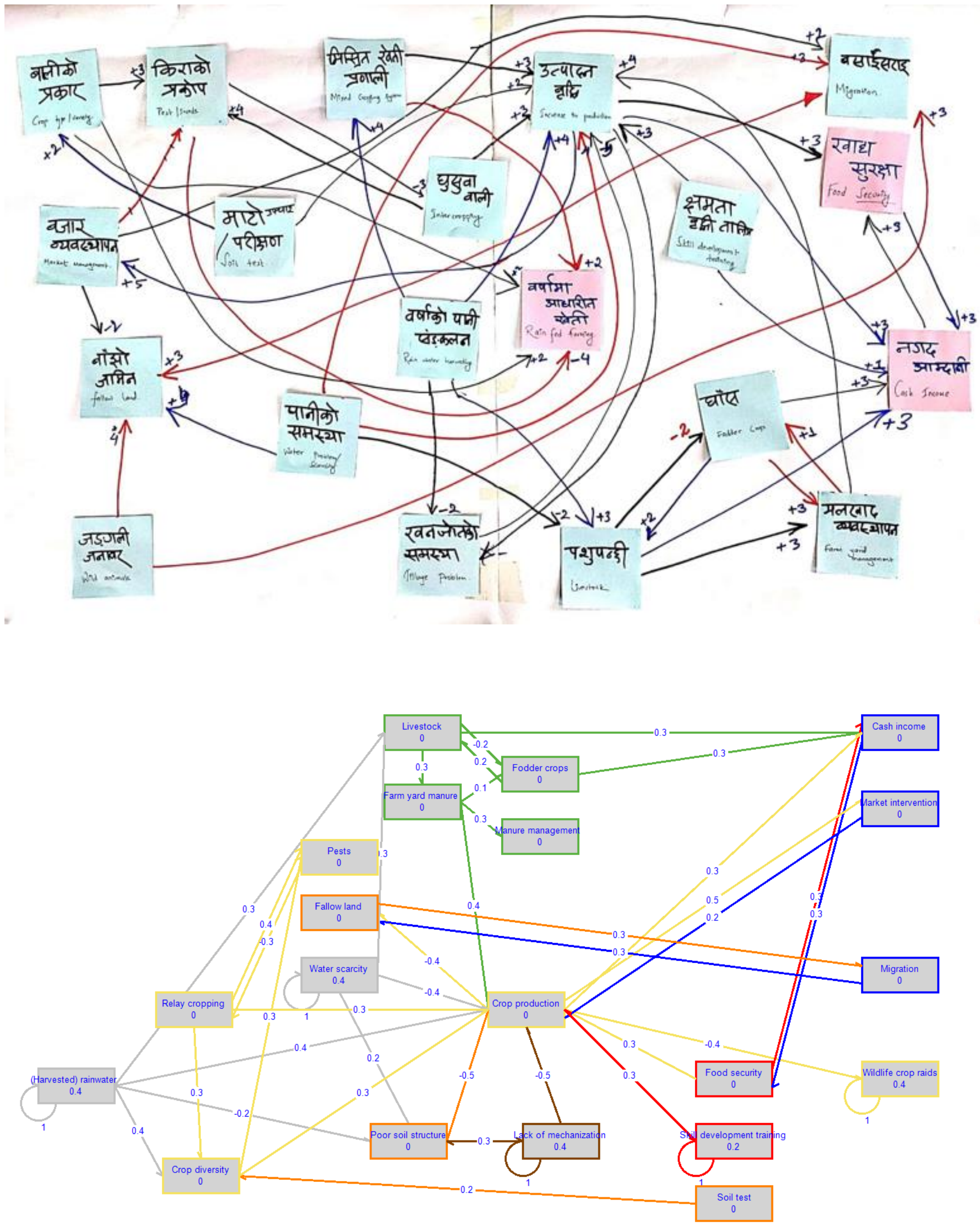


Figure 2. Fuzzy Cognitive Maps of the current rainfed farming system by the farmers of Ward 7, Khotang District, as drawn during the session (top) and translated to FuzzyDANCES (b). Note on color coding: yellow relates to crops, green to livestock, orange to soil, blue to economic, red to social, grey to bio-physical and brown to infrastructural components.

The metrics of the baseline FCMs provided insight into the structures of the models (**Table 1**). The structural analysis highlighted that the number of concepts and connections was highest for the MFS researchers. In terms of map density, however, the FCM constructed by the farmers contained the highest degree, indicating a more densely connected map. Zooming into the type of concepts, the percentage of ordinary concepts was similar across stakeholders, which hinted at high perceived interconnectedness of system components (Christen et al., 2015). Most transmitters were found in the FCM of the farmers and researchers, meaning that these stakeholder types perceived the system to be influenced by outside forces (i.e. biophysical factors such as slope and political factors such as governmental policy) to a higher degree compared to the local government. Regarding receiver concepts, the FCM of the local government contained the highest relative share, indicating that the model was more outcome-focused than the others. The receiver/ transmitter ratio was also highest for the local government, emphasizing that this stakeholder type perceived a smaller gap between the number of outcome variables and outside influences than the farmers and researchers. Lastly, for all stakeholder types, the hierarchy index is close to zero, suggesting similar potential adaptability and openness of the systems to changes.

Table 1. Metrics of baseline rainfed farming system maps stakeholders involved in MFS-project in Khotang district, Nepal.

Metric	Farmers	Local government	Researchers
Number of concept (Nc)	20	27	40
*Number of relations (Nr)**	34	52	74
Density	0.108	0.084	0.057
Number of ordinary concepts	13 (65%)	18 (66.7%)	25 (62.5%)
Number of transmitter concepts	6 (30%)	6 (22.2%)	12 (30%)
Number of receiver concepts	1 (5%)	3 (11.1%)	3 (7.5%)
Receiver/ transmitter ratio	0.17	0.50	0.25
Hierarchy index	0.018	0.011	0.006

*Nr excluding self- loops of drivers.

For all stakeholder types, crop production and precipitation were among the most central concepts, which was reflected in the high centrality degrees (Table 2). This confirmed the primary role of these components in the current farming system, where crop production relies on (harvested) rainwater during the monsoon season. Water scarcity was moreover recognized by all stakeholders as a primary limitation that inhibits year-round production, negatively affecting cash income and food security. Additionally, the FCMs highlighted other communality identified challenges hindering agricultural production, such as wildlife crop raids and lack of mechanization. Whereas the wildlife crop raids were a driver in the farmers map, it was an ordinary concept in the FCMs of the local government and researchers. This indicated that these stakeholders perceived wildlife crop raids as less of an uncontrollable external event than the farmers.

Table 2. Highest concept centralities of baseline rainfed farming system maps stakeholders involved in MFS-project in Khotang district, Nepal.

c_i	Farmers	Local government	Researchers
1st	5.2 Crop production	4.1 (Harvested) rainwater	5.6 Crop production
2nd	3.3 (Harvested) rainwater Water scarcity	3.7 Commercial farming	3.2 Cash income
3rd	2.5 Lack of mechanization	3.2 Mechanization	3.1 Food storage
4th	2.4 Wildlife crop raids	3.0 Capacity building program Monsoon crop production	2.9 Agricultural knowledge Livestock Water scarcity
5th	2.3 Skill development training	2.9 Food storage	2.8 Precipitation

3.2 Scenarios

The second group modelling sessions provided insight into how **climate change** was perceived to affect the farming system by the stakeholders. Table 3 shows the concepts that were provided by the stakeholders regarding climate change associated events and processes. Since the current climate is already characterized by monsoon and erratic rainfall and prolonged periods of drought, concepts regarding drought, erratic rainfall and high rainfall events were assumed to be increased in the climate change scenario. The concepts of increased drought, erratic rainfall, high rainfall events and temperature changes were mentioned by all stakeholder types, indicating the shared association of these concepts with climate change.

Table 3. Climate change scenario concepts per stakeholder type and corresponding outdegree.

Farmers	$od(v_i)$	*Local government*	$od(v_i)$	*Researchers*	$od(v_i)$
Livestock disease	0.40	-	-	Livestock disease	0.20
Drought	1.70	Drought	1.10	Drought	0.60
Erratic rainfall	1.30	Erratic rainfall	0.30	Erratic rainfall	0.50
Extreme temperatures	0.30	Temperature rise	1.80	Extreme temperatures	2.00
High rainfall events	0.80	High rainfall events	1.00	High rainfall events	0.60
Disappearance of birds	0.60	Deforestation	1.90	Delayed monsoon precipitation	0.70
Vegetation shift	0.10	Floods/ landslides	0.30	-	-

To simulate the effect of the **irrigation intervention** on the climate change scenario, the concept of irrigation was clamped with a state value of 0.5. The outdegrees of the irrigation concept were constructed based on the FCMs of the second group modelling sessions. All stakeholders perceived the irrigation intervention to influence the baseline system components of crop diversity (increase), crop production, livestock feed (increase), mechanization (increase), migration (decrease), (increase), water scarcity (decrease).

The relative changes of the concept values compared to the climate change scenario without the irrigation intervention were calculated (Figure 3). The climate change with irrigation intervention scenario had varying outcomes for the different stakeholder types. Starting with the impact on the target indicators, the values of cash income and food security increased in the model of the farmers and the local government. Cash income increased more strongly than food security, because cash income had more indegrees that were positively influenced by the intervention. For the researchers, the values of the target indicators did not trespass those of the baseline model (Figure 3). Moreover, in the researchers' model, the target indicators responded more equally to the intervention, with a slight steeper decrease of cash income than food security.

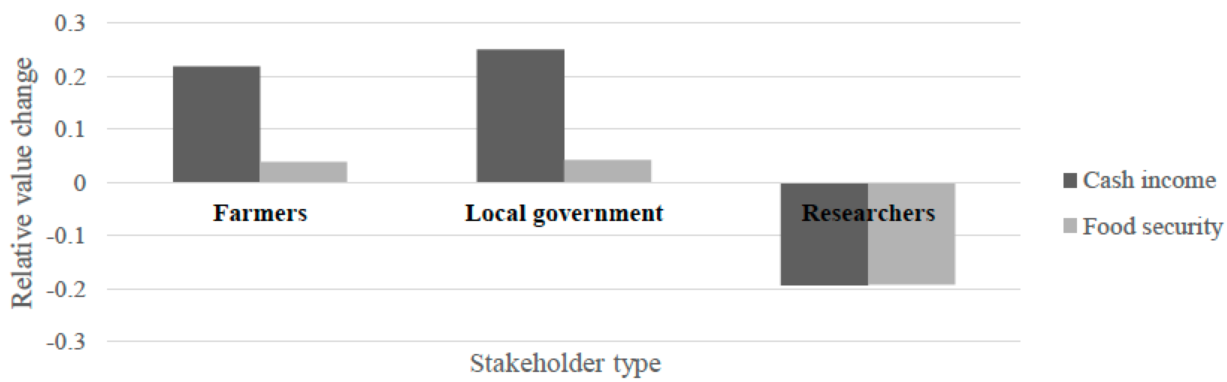


Figure 3. Inter-stakeholder comparison of the relative changes of the target indicator values under the climate change with irrigation intervention scenario compared to the baseline model.

4 Discussion

Fuzzy Cognitive Mapping proved to be a useful method to gain insight into conceptualizations of agroecosystems on the one hand, and to serve as a tool for inter-stakeholder comparison on the other hand. It allowed for identifying contrasting perceptions, but also areas of alignment, which can contribute to better informed intervention strategies (Christen et al., 2015). These findings are in line with other FCM studies conducted in Nepal (Alomia-Hinojosa 2022; Halbrendt et al., 2014), the broader South Asian context (Aravindakshan et al., 2021; Rajaram & Das 2010) and beyond (Christen et al., 2015; Gray et al., 2015). The importance of understanding belief systems of actors involved in agricultural projects and recognizing perceptual gaps is also acknowledged in literature based on non-FCM methods (Howell et. al., 2023; Lottering et al., 2022). Moreover, the strength of systems-thinking is widely known. Instead of applying a reductionist view on individual system aspects, it considers all components and their interdependencies, which is crucial for implementing holistic and sustainable solutions (Neupane et al. 2023).

This research underscored the importance of understanding the differences in perceptions among stakeholders involved in agricultural development projects and to embed these diverse viewpoints into implementation strategies. It highlighted the value of considering both local knowledge and experiences of farmers alongside the system-level approaches of the local government and researchers. Moreover, the differing views on the potential of irrigation to enhance cash income and food security in times of climate change highlighted the need for a shared understanding of the expected outcomes of any future irrigation interventions.

By introducing the irrigation intervention to the climate change scenario, its potential mitigative properties were unraveled. Regarding the target indicators of cash income and food security, the values increased compared to the baseline scenario (and the climate change scenario) in the model local government. In the model of the farmers, only food security increased. For the researchers, the intervention did not increase the values of the target indicators. In general, the FCM of the local government showed most potential of the irrigation impact on the farming system, as a third of the total number of concepts moved towards the preferable state. For the farmers, less concepts moved into the desirable direction, but the concepts with the highest centralities (crop production and water scarcity) did. In the researchers' FCM significantly less concepts improved, hinting at additional needed measures mitigate the impact of climate change on farming systems.

This research focused on just three stakeholder types, which excluded other important stakeholders involved in a potential irrigation intervention such as local vendors or the National Agricultural Research Council (NARC). Moreover, intra-stakeholder differences such as gender and age were not considered. Heterogeneity in socioeconomic characteristics can, however, influence the perceived understanding of farming systems (Aravindakshan et al., 2021). Considering the largescale outmigration of male farmers and resulting feminization of area makes the perception of women who stay behind especially important. For future research, the inclusion of other relevant stakeholders and intra-stakeholder variation, with a particular focus on women is crucial. Moreover, fruitful follow-up research would be to study the question whether FCM can improve inter-stakeholder dialogues and thereby enhance the effectiveness of agronomic interventions.

5 Conclusions

Constructing FCMs in participatory group modelling sessions provided insight into the components, interrelations, and performance of rainfed farming systems as perceived by farmers, local government officials and researchers. The FCMs captured the mental models of the different stakeholders involved in a potential irrigation intervention, forming a base for comparison of the system conceptualizations and introducing scenarios to investigate the models' responses to external shocks (climate change) and a possible intervention (irrigation).

The FCMs revealed both overlap and gaps among the stakeholders' system understandings. The discrepancies were not necessarily an outcome of contrasting concepts, but rather of the different scales on which the FCMs were based. The landscape-level perspective of the local government and researchers added additional system components to the farm-level perceptions of the farmers.

The group modelling sessions provided valuable knowledge about how the spatially different phenomenon of climate change manifests at local level, as well as its imagined future impact. The stakeholders had similar conceptualizations of processes and events induced by climate change and their impact on the rainfed farming system. Based on the stakeholders' belief systems, an irrigation intervention could potentially mitigate the gravity of the negative impact of climate change on the farming system, and for some components, even improve it compared to the current situation. However, the analysis of the scenarios illustrated that the irrigation intervention was a decision variable only in the models of the farmers and local government. As a result, the FCMs of the farmers and local government showed more potential of the irrigation intervention to enhance the target indicators of cash income and food security than the researchers' model. FCM helped to disentangle this finding by pinpointing conceptual discrepancies, as well as differences in perceived causality (Christen et al., 2015). The identified perceptual gaps can potentially provide entry-points for improved inter-stakeholder coordination to ensure long-term impact of interventions and ultimately contribute to resilient farming systems.

6 Literature

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