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RESEARCH ARTICLE

Adapting agroforestry to upland farming systems: narratives from smallholder farmers in Northwest Vietnam

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Abstract
Fruit tree–based agroforestry has been promoted as an alternative farming practice in upland Northwest Vietnam to replace monocultures of staple crops. Although many studies have focused on evaluating the performance of agroforestry systems at the plot level, research on how farmers perceive and evaluate agroforestry considering whole-farm contexts is limited. We explored the perceptions and reasoned management decisions of agroforestry farmers to uncover challenges that hinder the wider use of agroforestry, and we assessed farmers' strategies for effective management of adoption challenges. We combined the Q methodology and the systems thinking approach. With the Q methodology, we explored prevalent discourses among the members of the farming community on the impact of agroforestry. Systems thinking elucidated a system-wide understanding of farmers' adaptive decision-making processes. By combining the two approaches, we uncovered the dynamics that shape farmers' perceptions and the rationale behind their management of the adoption process. Through the Q method, we identified three distinct discourses among participants. Two of these discourses are in favor of agroforestry, highlighting its beneficial impacts on livelihoods and the environment, e.g., through diversification of household income and through soil erosion control. We also generated a collective development pathway outlining how farmers navigated and adapted agroforestry practices to overcome adoption challenges through a whole-system approach to farm resource management. We identified structural barriers, such as unstable farm-gate prices, that may need high-level interventions. Our study adds a new dimension to the assessment of agroforestry through farmers' perspectives and contributes to the existing body of research on knowledge systems in agroforestry. Considering farmers' views and their ways of reasoning during innovation processes may allow tailoring appropriate innovations by accounting for unique farm situations and local farming systems. Such locally generated knowledge will have relevance for real-world contexts and therefore be useful for guiding actions.

Keywords Agroforestry · Farmer perception · Q methodology · Systems thinking · Northwest Vietnam

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1 Introduction

Agroforestry is often promoted as a multi-benefit land use practice that increases the resilience of agricultural landscapes across tropical and temperate zones (Kuyah et al. 2019; Do et al. 2020b; Nair et al. 2021). However, farmers who adopt the practices still face many challenges in the transition towards viable agroforestry-based livelihoods. Agroforestry adoption requires drastic changes in cropping patterns, including the integration of new components. The change may carry with it economic trade-offs and risks for adopting farmers, especially those with limited resources. Reasons for this are complex interactions that agroforestry adds to the farming system, as well as the long-term

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planning horizon involved in the cultivation of trees (Do et al. 2020a). Meanwhile, scientific experiments might be insufficient to evaluate agricultural innovations such as agroforestry, especially within the context of small-scale farms in the tropics and sub-tropics, where farm management is diverse and heterogeneous. The heterogeneity is the result of diverse strategies, modes of thinking, and aspirations that farmers may have with regard to their social and natural environments, in addition to a diversity of ways in which farmers organize their livelihoods (Stuiver et al. 2004). During the adoption process of new farming practices, farmers often make significant adaptations to the methods introduced to them by researchers (Stuiver et al. 2004). This can cause research-oriented designs to lose their predictive power when put into the real context of farm operations. Figure 1 demonstrates the diversity of farmer-managed landscapes including agroforestry (intercrop of fruit trees, maize, and fodder crops), paddy rice, sugarcane, and community forest. Given the adaptive nature of farm management, understanding the underlying logic and rationale behind farmers' management decisions is important when aiming at a sustainability-oriented transition.

Farmer perception often involves various psychological constructs such as the farmer's knowledge, attitudes, and beliefs regarding certain aspects of the farming system. A range of factors can influence and shape perception, including an individual's characteristics, personal experience, knowledge, and cultural beliefs, as well as local environment conditions (van der Linden 2015). These factors often vary greatly among farmers. Farmers' perceptions are therefore expected to vary accordingly, which may result in very diverse behaviors among farmers. In addition, farmers draw from a rich understanding of local resources and often engage strongly in maintaining socio-ecological systems in the face of changes and disturbance. Their views and perceptions, therefore, can provide contextual insights on what facilitates or hinders the transition, and on how systems can be designed and managed to better engage in a diversity of contexts. However, such local knowledge has remained under-exploited during the innovation process within the context of the prevailing dominant scientific knowledge system (Stuiver et al. 2004; Caron et al. 2014). Therefore, in this study, we aimed (1) to identify different narratives that explain barriers for the wider use of agroforestry, and (2) to explore the reasoning behind management decisions for effective management of adoption challenges among agroforestry-practicing farmers in Northwest Vietnam. The findings may aid social learning and provide pointers on which outreach interventions may be effective in promoting wider adoption.

Fig. 1 Agroforestry managed by farmers in a mixed cropping landscape. Photo credit: Hoa Do.

2 Materials and methods

2.1 Agroforestry projects in Northwest Vietnam

We targeted agroforestry-practicing farmers in Son La, a province in northwestern Vietnam. In the region, agricultural activities mostly happen on slopes and have been dominated by monocropping systems of staple crops (mainly maize, upland rice, and cassava) and sugarcane. Son La province has experienced a rapid expansion of intensive maize monocropping on slopes with the introduction of hybrid varieties and intensive use of synthetic fertilizers. The expansion of the maize area has impacted the environment through deforestation, intensive ploughing, and shortened fallow periods contributing to widespread soil erosion and land degradation. The depletion of soil fertility has reduced maize yields dramatically. The yield reduction has been exacerbated by climate change, which has been linked to increasingly frequent and unpredictable drought periods, especially at the critical stage of maize growth and development. Local livelihoods have been highly vulnerable. The province was one of the foci of recent efforts by World Agroforestry (CIFOR-ICRAF), who undertook a two-phase agroforestry project "Developing and promoting market-based agroforestry and forest rehabilitation options for Northwest Vietnam" (AFLI) from 2011 to 2021, which was funded by the Australian Centre for International Agricultural Research (ACIAR) and the CGIAR Research Program on Forests, Trees and Agroforestry. The aim was to enhance the livelihoods of smallholder families by introducing and promoting more sustainable land management practices. Through the project, agroforestry was first introduced via replicated on-farm trials of several agroforestry settings for scientific assessments. Research efforts have been invested to examine the agronomic, economic, and environmental performance of replicated on-farm trials (Do et al. 2020a, b, 2023). Since 2015, exemplary landscape models of agroforestry have been established, alongside a government resolution promoting the cultivation of fruit trees on slopes (2015–2020), to encourage local participation within a larger area. The adoption of tree-based practices has transformed the structure of local land use from intensive monoculture of cash crops to more diverse and mosaic land use patterns. In this study, we directed our focus towards farmers who participated in the exemplary landscape models in two villages in Hat Lot Commune in Mai Son District of Son La (Fig. 2). Fruit tree-based agroforestry was introduced to participating farmers as an alternative to conventional monocropping systems. The participation of farmers in the exemplary landscape models was based on their willingness to participate and on the farmers' field plots being close to each other, to allow investigation of a landscape of agroforestry practices.

2.2 Research approach

We combined the Q methodology (Stephenson 1935) with systems thinking (Fig. 3). We used the Q method to uncover perceptions of farmers who have adopted agroforestry

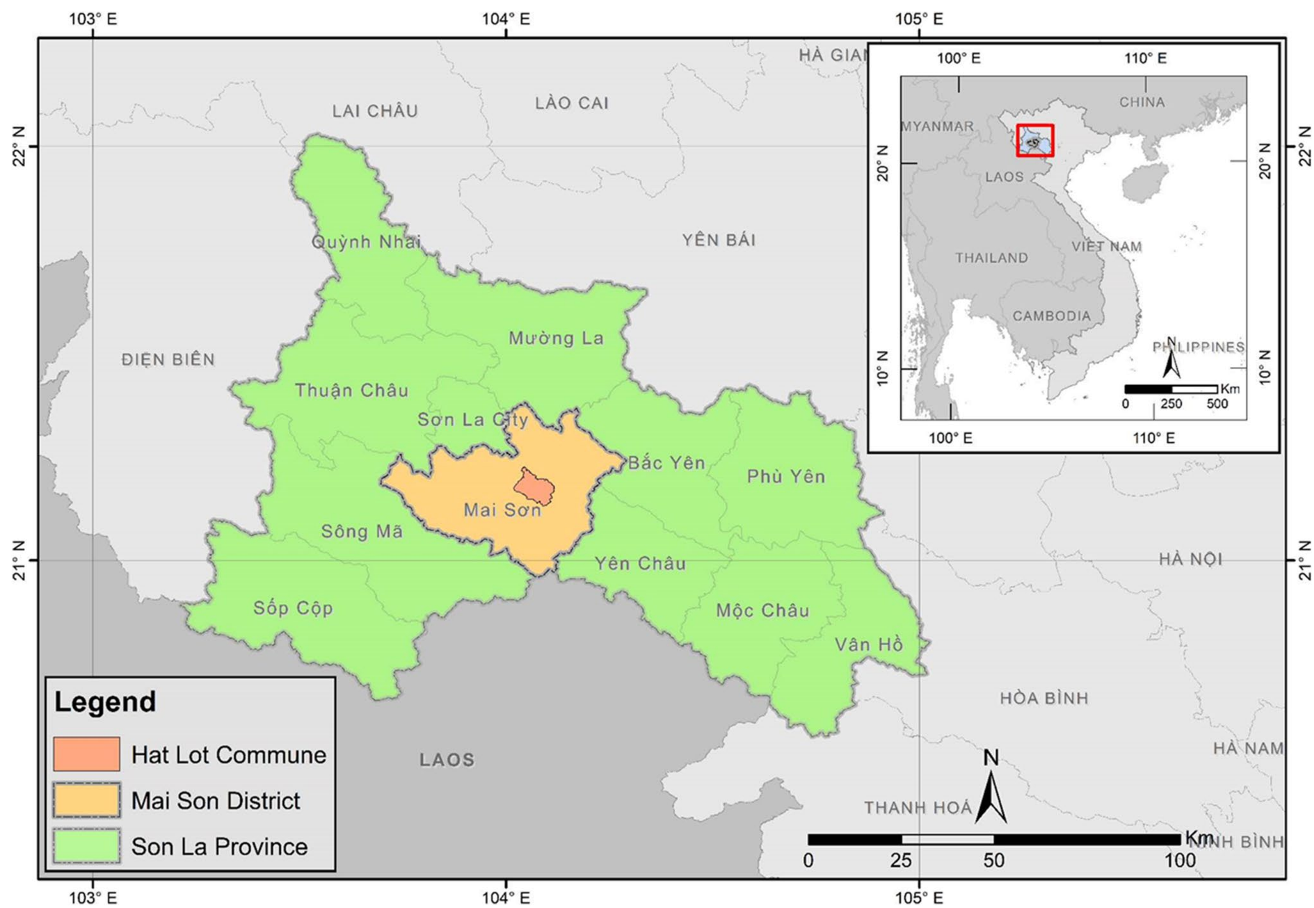
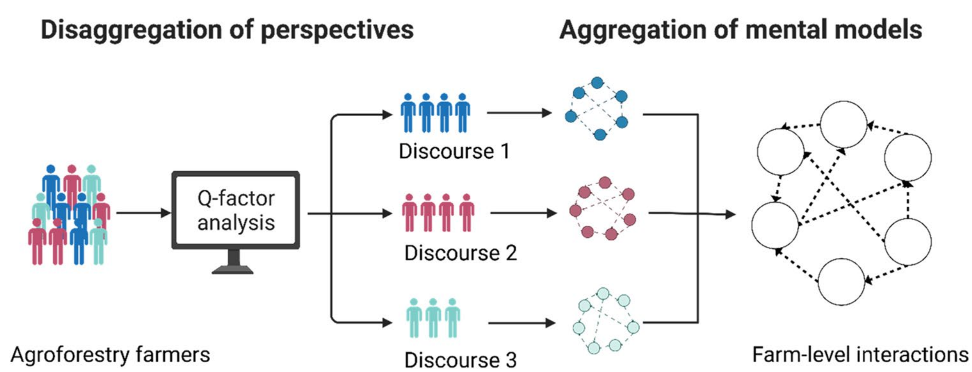


Fig. 2 Study location in Northwest Vietnam.

Fig. 3 Protocol combining the Q method and systems thinking to study farm-level impacts of agroforestry from a farmer perspective. Created with BioRender.com.



practices. Systems thinking was applied to elicit farmers' mental models, through which linkages between knowledge and action in managing the adoption can be captured.

2.2.1 The Q method for studying human subjectivity

The Q method is a semi-quantitative approach to facilitate the understanding of highly complex and socially contested concepts and subject matters in which human subjectivity is involved (Watts and Stenner 2005). The method seeks to uncover patterns of perspectives (discourses) within a group of actors on the topic of interest (Mukherjee et al. 2018). It provides a robust and systematic method to reveal consensus and disagreement among respondents. Q has been increasingly used across disciplines for multiple purposes such as policy evaluation (Zabala et al. 2017), understanding decision-making (Alexander et al. 2018), and guiding participatory processes (Sumberg et al. 2017; Truong et al. 2017; McHugh et al. 2019; Buckwell et al. 2020). The three main steps involved in the Q method are sorting, analytical process, and interpretation (Rost 2021). In its most frequent form, the Q method consists of selecting a set of statements from a universe of statements (concourse) on a certain concept (Watts and Stenner 2005) and asking respondents to sort them over a grid distribution (e.g., Fig. 4) based on their psychological significance, e.g., from "most agree" to "most disagree" (Mukherjee et al. 2018). The distribution shape can be predefined or freely defined throughout the interviews (Rost 2021), which is usually decided by researchers (Zabala 2014) based on the research context. The set of statements is ideally a representative sample of possible expressions on the issue of interest, gathered from all possible points of view. The analytical process synthesizes the data into a typology of perspectives using multivariate data reduction techniques such as principal component analysis (PCA) and factor analysis (FA). In contrast to regular PCA and FA, the Q method correlates respondents (Stephenson 1935; Zabala 2014) rather than variables. These data reductions are then followed by a set of analytical steps specific to the Q method to obtain a clear interpretation of the statements (Zabala 2014; Zabala and Pascual 2016).

The Q method employs a few key terms to describe the analysis process and interpret the results: Q-sorts, factors, factor loadings, *z*-scores, and factor scores (Zabala and Pascual 2016):

- A Q-sort is an array of integer values that a single respondent assigns to statements when arranging the statements over the given frequency distribution.
- A factor or discourse is a hypothetical best-representative respondent of those with similar views, which is extracted from the sample of Q-sorts.
- A factor loading is the correlation of each Q-sort with each factor. A respondent who is most similar to the factor has the highest loading.
- The *z*-score is calculated for each statement in each factor. The score is a continuous value presenting a weighted average of the values given to the statements by Q-sorts that are most closely related to the factor. It is used to determine statements that distinguish a factor from the other extracted factors (Zabala et al. 2017).
- Factor scores are integer values that a factor would assign to statements. They are used to reconstruct the Q-sort of a factor.

Statements are ranked relative to each other to reflect the salience of the statement within each factor and the distance of the statement compared to that of other factors (Zabala et al. 2017). The ranking of statements is based on *z*-scores and factor scores, which are also used in the final interpretations.

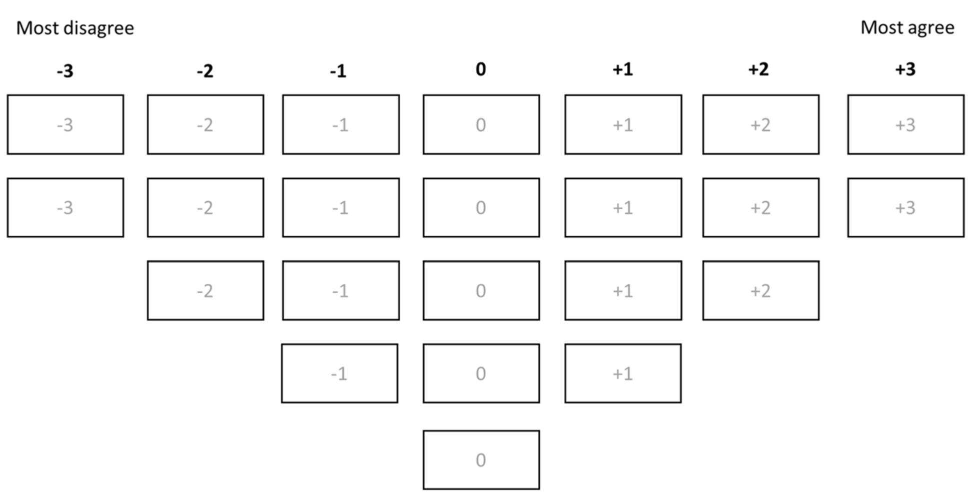


Fig. 4 Grid distribution used for statement ranking in the Q method.

2.2.2 Systems thinking for system-wide understanding

Systems thinking emphasizes the recognition of dynamic interdependence between components of a system and is commonly used to understand and manage complex systems (Levy et al. 2018). By considering interdependencies, systems thinking can help to avoid unintended consequences of decisions that focus on only one part of a system and may help address complex problems with uncertainty and diverse causal pathways (Head and Alford 2015). The four successive levels of systems thinking are (1) observing events, (2) identifying patterns of behavior over time, (3) exploring the underlying structures that drive those events and patterns, and ultimately (4) unveiling the mental model describing the values and perceptions of decision-makers (Aivazidou and Tsolakis 2022). The resulting mental models allow decision-makers to better understand their perceptions of problems and courses of action and likely impacts and outcomes. Systems thinking, therefore, allows for informed decisions. Systems thinking has been applied in various domains including healthcare (Peters 2014; Stalter and Mota 2018), agriculture and sustainability (Levy et al. 2018; Jagustović et al. 2019; Bustamante et al. 2021; Desbois et al. 2021; Groundstroem and Juhola 2021), project management (Charbonnier et al. 2017), and education (Shaked and Schechter 2019; York et al. 2019).

In technical terms, systems thinking often uses Causal Loop Diagrams to facilitate the process of thinking and the analysis of the system of interest (Jagustović et al. 2019; Groundstroem and Juhola 2021). Causal Loop Diagrams capture the structure of a system by mapping out cause-and-effect interactions and feedbacks within the system (Aivazidou and Tsolakis 2022). They consist of three basic components: (1) causality (causal relationship between variables), (2) polarity (direction of the causal links), and (3) feedback loops (closed links of variables) (Cavana and Mares 2004). Variables are connected by arrows to indicate causal links between them. An arrow with a positive sign (+) represents a positive link, indicating the same direction of change for the two connected variables. In contrast, an arrow with a negative sign (-) represents a negative link, indicating the opposite direction of change in the two variables. After all the variables and links are mapped, feedback loops, which are closed loops of variables (Cavana and Mares 2004), might appear. By connecting variables and links of important loops, one can create a coherent and holistic story of a system. A feedback loop can be either reinforcing (R), if events or behaviors created by the variables in the loop amplify each other, or balancing (B), if some variables create counteracting changes, resulting in equilibrium (Cavana and Mares 2004; Lin et al. 2020). The most common way of assessing feedback loop effects is to count the number of negative links in the loop. An even number of negative links results in a reinforcing loop, and an odd number of negative links results in a balancing loop (Lin et al. 2020). The causality, in some cases, can be characterized by time delays between taking a decision and its effects. The feedback loops with delay, whether for long-run or short-run responses, enable the system to cope with and adapt to change in order to sustain its function. Long delays and indirect consequences can make it difficult to recognize the feedback structure and its impacts (Jagustović et al. 2019).

2.3 Data collection and analysis

2.3.1 Q methodology

Design and administration of the Q study We generated a comprehensive sample of statements (concourse) based on expert consultation and in-depth interviews conducted with 70 farmers, as well as through extensive field observations. Local extension officers and village heads supported us in selecting 70 farmers in two villages, who are currently practicing agroforestry, based on a range of farm characteristics (Table S1, Supplementary) and the farmers' willingness to engage in the research. The generated concourse covered topics on farm-level impacts of agroforestry adoption with a main regard to perceived benefits and challenges of the practices. There was a high level of redundancy among the statements. We selected the most frequently mentioned statements by both experts and farmers. Those statements focused on investment level, profitability, relative advantage of labor demand, pests and diseases, management complexity, and complementary impacts (soil erosion, climate impacts, income diversification, and livestock production support). Less frequently mentioned statements related to herbicide use, manure application, and farmers' knowledge on agroforestry were also considered because they appeared highly relevant to the study area context. We included additional statements on farmer cooperation, adoption level, and the possibility of dis-adoption due to their relevance to the context of our study. We discarded statements mentioned only by experts on topics such as landscape aesthetics, benefits from tourism, or agroforestry certification schemes (VietGAP or GlobalGAP), which were not closely related to farm-level interactions and did not seem relevant to the interviewed farmers. The final Q set contained 23 statements (Fig. 5). The number of statements is low in comparison with other Q studies; however, the set sufficiently covered the topics that we aimed to explore in this study. We attempted to create a low number of statements for more stable and reliable Q-sorts given the limited literacy of our participants. During the sorting process, we found that participants could understand and manage the given number of statements well. The selected statements were randomly

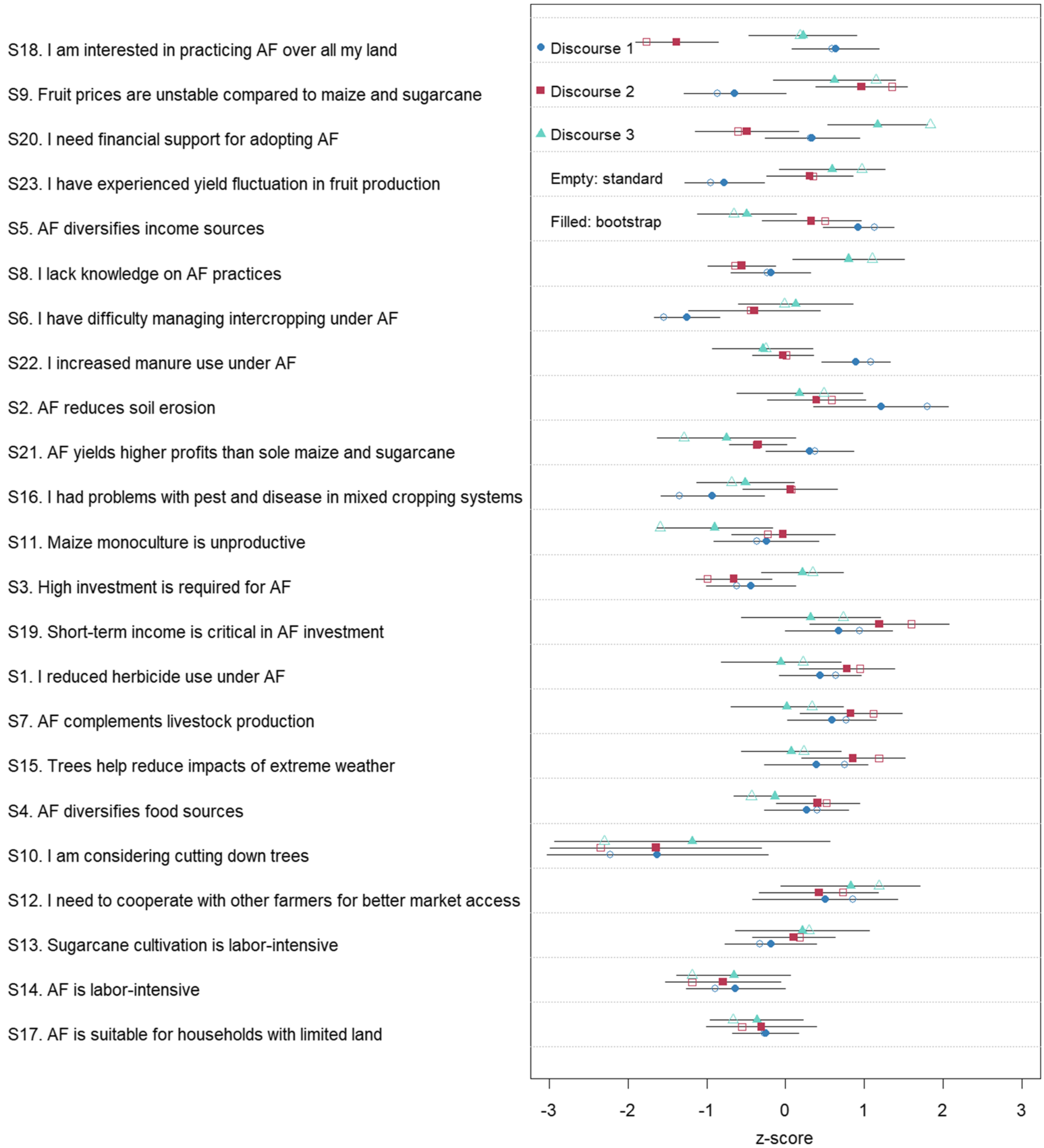


Fig. 5 Z-scores of statements on farm-level impacts of agroforestry (AF). The statements are ranked based on the descending difference in z-scores of three factors (distinguish to consensus). Error bars represent 95% confidence intervals (CIs) of z-scores.

numbered and each was printed on one card. The stack of cards was then provided to respondents, to be ranked over a given grid distribution. We predetermined the distribution with a quasi-normal shape (Fig. 4), as this was convenient for our participants. The forced distribution helped encourage thinking and reflecting efforts of participants to ensure that each statement was compared and ranked relative to each other statement, in order to capture their interdependence and complexity (Rost 2021). On the other hand, the distribution, whether predetermined or free, has been statistically shown to not make a noticeable contribution to the emergence of factors (Brown 1980).

We piloted Q sorting with seven farmers and one extension officer to make sure statements were clearly worded and transparent. The piloting also helped us anticipate situations that might arise during the actual implementation. We followed maximum variability sampling (Zabala et al. 2017) to include a broad range of smallholder farmers. Of the 70 farmers who participated in our face-to-face interviews, we selected 40 with wide ranges of land area, level of agroforestry adoption, level of livestock production, diversity of livelihoods, and diversity in attitudes toward agroforestry, based on results from the exploratory interviews.

The Q-sorting was conducted face-to-face with the 40 selected farmers. For each participant, we explained the sorting procedure and associated materials (i.e., the stack of cards and the printed frequency distribution grid), with the instruction "Please rank the statements regarding your opinions on agroforestry adoption in the context of your farm operation." To facilitate the sorting, participants were advised to initially divide statements into three piles of *agree, disagree*, and *neutral* to reduce the number of cards for each level of assessment and then distribute each set of cards to the corresponding grid cells. Participants found it easy to manage the number of statements in this way. Farmers had a chance to revisit and change the position of cards if they found this necessary. The complete response was recorded on a printed sheet with the respondent's basic information. The ranking exercise was followed by a post-sorting interview where respondents provided in-depth rationale behind their ranking of statements, especially for the statements in extreme positions. This information was used to support the interpretation of the results.

Reducing Q-sorts to factors The set of 40 Q-sorts collected from all participants was structured in a two-dimensional matrix with statements in rows and Q-sorts in columns. Q-sorts were then correlated to generate a correlation matrix. Fewer factors that explained most of the variance were extracted from the correlation matrix using PCA. The number of factors to extract was decided based on the elbow rule and on the eigenvalues of components. The elbow rule suggested two factors while the eigenvalues demonstrated five factors could be retained. We explored the results that emerged when using different numbers of factors (from two to five factors) and decided to retain three factors based on the number of respondents loaded in each factor, the percentage of explained variance (Table S2, Supplementary), and the ease of result interpretation. The extracted factors were then rotated using the *varimax* technique (Zabala 2014). This resulted in a matrix of factor loadings that correlated Q-sorts with the rotated factors. Based on the raw data and the factor loading, the most representative Q-sorts for each factor were identified. *Z*-scores and factor scores within each factor were then estimated and identified for each statement.

Accounting for uncertainty in the outcomes To obtain more precise levels of confidence in the results and to enhance the accuracy of the interpretation, we applied bootstrap re-sampling (Zabala and Pascual 2016) to our original sample of Q-sorts. The bootstrap with replacement was implemented as a first step before Q-sorts were correlated. For each bootstrap repetition, a resample of 40 Q-sorts was generated from the original set of Q-sorts. A full Q analysis was performed for each resample of Q-sorts. We ran 3000 bootstrap steps and repeated the Q analysis on the 3000 generated resamples. This resulted in, for a given statistic (i.e., factor loadings and z-score), a distribution which provided the estimates of the outcomes with uncertainty (mean and standard deviation). Bootstrapping Q was implemented using the *qmethod* (Zabala 2014) package in the R statistical language (R Development Core Team 2022).

2.3.2 Systems thinking with agroforestry farmers

We applied the systems thinking approach to complement the Q method through a process of collectively reflecting on the dynamic understandings of farmer perceptions from adaptive decision-making viewpoints. We conducted systems thinking sessions through a series of workshops with three groups of farmers, representing three discourses in the Q study.

For each group, farmers were invited to reflect on the dominant changes they observed or made on their farms since adopting agroforestry. We asked farmers to list elements within their farms, reflecting on what has affected and been affected by agroforestry adoption. Each element listed by farmers was written on an empty card by our facilitator and placed on a large paper board. For each element, farmers identified the direct influence by reflecting on the question "*what does this influence and what influences this*?" The researcher drew arrows indicating direct links stated by farmers. Farmers then described the direction of the influence guided by IF-THEN dynamics (Jagustović et al. 2019). For all changes in the causal variables involved in these IF-THEN statements, farmers determined whether they expected other elements impacted by the variable to increase or to decrease. If farmers stated that the change of one variable caused a change in another variable in the same direction, the researcher added a positive sign (+) to the arrow connecting the two variables. The negative sign (-) was placed if the change in one variable caused a change in the opposite direction in another variable. At this point, new elements were introduced as intermediate cause-and-effect relationships. The IF-THEN dynamics were also applied to detect the direction of links between the added elements.

Participants identified important feedback loops and discussed how these loops would interact with each other to create the system dynamics. We defined the concept of feedback loop as the case *when a change in one element leads to a change in the same element after some tim*e (Jagustović et al. 2019). The researcher illustrated an example of a feedback loop in the working diagram and then invited farmers to identify and describe other feedback loops. Loops were highlighted as dominant when farmers pointed them out as the most dominant dynamics that they observed in their farm environment since adopting agroforestry.

In addition to paper-based documentation, we digitally recorded and transcribed the results of the group work and discussions during the workshops to support the process of model construction and interpretation. We unified the conceptual diagrams from the three groups by including both common and distinguishing elements and links to ensure diverse presence of elements and their causal structure from different points of view. We conceptualized the outcomes from the systems thinking exercise into a Causal Loop Diagram using the Vensim PLE 9.2.4 software (Ventana System, Inc.).

3 Results

Forty farmers participated in the Q study, including 21 males and 19 females, and ranging between 20 and 64 years of age (median age of 46 years). All farmers had experience with agroforestry and kept livestock, with 87.5% owning cattle. Farm sizes ranged from 0.65 to 4 hectares (median of 1.2 hectares), scattered over 1 to 7 plots of land (median of 4 plots). Cropping systems were diverse but featured three major systems including maize, sugarcane, and fruit tree-based agroforestry systems. Small parts of the land were devoted to the production of fodder and other annual crops such as cassava and achira (*Canna edulis*). The current scale of agroforestry area per farm ranges from 22 to 100% of farm land (median of 54%). Intercrops of fruit trees (e.g., longan, mango, and plum), annual crops (e.g., maize, achira, and cassava), and fodder grass were the most common agroforestry designs in the area.

3.1 Discourses among farmers on agroforestry adoption

Three main discourses were identified by the Q analysis, explaining 50% of the variance in farmers' rankings of statements. Discourse 1 explained 20% of the variance and was contributed by 14 participants. Discourse 2 explained 17% of the variance, corresponding to 12 farmers. The third discourse included 8 respondents and explained 13% of the variance. *Z*-score (Fig. 5) and factor scores (Table S3, Supplementary) were compared to identify those statements that characterize the discourse and distinguish each discourse from the others.

In general, there was a strong consensus among farmers that they are unlikely to abandon integrated trees (S10) since they perceive trees as a long-term investment. Farmers also agreed that agroforestry is not a labor-demanding practice (S14) compared to sugarcane (S13) and that cooperation among tree-growing farmers would benefit market access for their fruit products (S12). By contrast, major distinctions in farmer perspectives refer to the scale of intended land use for agroforestry (S18), perceived stability of fruit price compared to prices of maize and sugarcane (S9), and the need for external assistance to support adoption (S20).

Discourse 1 The first discourse represents farmers who display a strong belief that their households have benefited from agroforestry adoption. This discourse emphasizes the role of agroforestry in reducing soil erosion (+3, S2) and diversifying sources of income (+3, S5). Farmers have applied more manure (+2, S22) with the presence of trees and they benefit from high availability of manure from increased livestock production as a result of agroforestry adoption (+1, S7). They do not have trouble with complex management in agroforestry or pests and diseases in their mixed-cropping systems (-3, S6 and -2, S16), and they do not see agroforestry as a labor-demanding practice (-1, S14) compared to sugarcane (0, S13). They consider earning short-term income from annual crops as a strategy in agroforestry investment (+2, S19). They can afford the investment level of agroforestry (-1, S3), and they have a neutral attitude toward external financial support to adopt the practice (0, S20). They show little concern about the fluctuation in prices and yield of fruits (-2, S9 and S23 respectively), which might imply that they have adaptive strategies. Seeing opportunities from agroforestry rather than its obstacles, the farmers in discourse 1 would likely scale up agroforestry over their land (+2, S18) and are unlikely to abandon the planted trees (-3, S10).

Discourse 2 The respondents associated with discourse 2 perceived benefits from agroforestry to some extent, but also emphasized challenges of the practice. They assigned the greatest importance to short-term income from an agroforestry investment (+3, S19). They could afford the investment level of agroforestry (-2, S3) and were therefore not in strong need of external support to adopt the practice (-1, S20). Agroforestry provides fodder for animal husbandry (+2, S7), reduces herbicide use (+2, S1), and dampens the impacts of extreme weather conditions (+2, S15). Farmers associated with discourse 2 did not perceive agroforestry as a labor-demanding practice (-2, S14) compared to sugarcane (0, S13) and were quite confident about their knowledge and experience about the practice (-2, S8). They are unlikely to cut down trees (-3, S10), but unlike farmers in discourse 1, they expressed a lower intention to expand agroforestry to the whole farm (-3, S18) because they perceived fruit prices to be unstable compared to other cash crops (+3; S9). They also perceived the profits from agroforestry as not being higher than those from the two alternatives of maize and sugarcane (-1; S21).

Discourse 3 Discourse 3 assembles farmers who emphasized stronger views about the challenges of agroforestry adoption rather than its benefits. From their point of view, monocultures of maize are still productive cropping systems (-3, S11). These farmers rely on external support to adopt agroforestry (+3, S20), since the practice requires higher levels of investment than they can afford (+1, S3), and they do not consider agroforestry to be profitable compared to the alternatives (-2, S21) due to the perceived fluctuations in both fruit yield and price (+2, S9 and S23). They have a strong belief that cooperation with their peers would bring benefits in market access for their products (+3, S12). They reported a lack of knowledge on agroforestry practices (+2, S8). Discourse 3 agreed with the other two discourses that agroforestry is not a labor-demanding practice (-2, S14) compared to sugarcane (+1, S13) and pest and disease issues are not a concern in mixed agroforestry cropping systems (-2, S16). They are unlikely to abandon the planted trees (-3, S10) and intend to expand agroforestry areas (+1, S18).

3.2 Discourses and farmer characteristics

Discourses were related to some observed characteristics of respondents, such as location, gender, age, land area, level of adoption (% land occupied by agroforestry), livestock production (number of cattle owned), crop diversification (number of crop settings), and livelihood diversification (number of livelihood activities). The established associations reflect correlation and not necessarily causal relations. Due to the small sample size, the analysis should also be considered exploratory.

We used the X2Y metric, an alternative to correlation coefficients, which works in the presence of both categorical and numeric variables (Ramakrishnan 2021). X2Y is inspired by the mutual information concept (Learned-Miller 2013). The metric quantifies the relative reduction (in %) in prediction error between a baseline model of Y without knowing X and a model predicting Y given knowledge on X. The baseline model is determined as the average of Y when Y is continuous and the most frequent value when Y is categorical. Classification and regression tree (CART) is applied for predicting Y given X. The relative reduction in prediction error is then calculated using mean absolute error and misclassification error for continuous Y and categorical Y, respectively. A detailed description of the approach and R script for the metric implementation can be found in Ramakrishnan (2021). Table 1 shows the results for only the pairs of variables with non-zero X2Y.

In general, no association between farmers' discourses and the tested variables appeared to be substantive except for location, age, and land area, for which the 95% confidence intervals of X2Y did not include 0.

Table 2 presents characteristics that appear to correlate with discourses. Each discourse is dominated by farmers in specific locations which, in this study, represent geographic proximity within the two villages. The location variable may characterize farm structure, farming style, or peer influence. Farmers in discourse 1 are older and own less land than those in discourse 2 and discourse 3. Gender and livestock showed insignificant association in the analysis; however, they showed some patterns in relation to discourses (Table 2). Discourse 1 assembles more men than women while the opposite is true for discourse 3 where the number of females is higher. Farmers in discourse 1 and discourse 2 own more cattle than farmers in discourse 3.

Table 1 Association between farmer discourses and farmer characteristics.

X	Y	X2Y	Bounds of 95% confidence interval	
			Lower	Upper
Location	Discourse	35.0	10.9	70.0
Age	Discourse	35.0	8.9	58.9
Land area	Discourse	30.0	4.4	53.8
Livestock	Discourse	25.0	−3.4	50.0
Level of adoption	Discourse	20.0	−7.7	40.0
Gender	Discourse	10.0	−16.4	20.0
Crop diversity	Discourse	5.0	−28.5	10.0

3.3 Discourses and farm models

Causal Loop Diagrams were generated from systems thinking sessions for discourse 1 (Fig. 6), discourse 2 (Fig. 7), and discourse 3 (Fig. 8) to illustrate the dynamics of farm processes and farmers' actions in response to the changes in land use configuration in the context of agroforestry adoption. Farmers identified all elements within the boundary of farm operations and two elements outside as having significant impacts on the system. The two external elements were the farm-gate price of fruits and climate change impacts (bold text in Fig. 6 and Fig. 7 and Fig. 8). The main components (shaded boxes and bold text in Fig. 6 and Fig. 7 and Fig. 8) can be considered decision variables, which may change and interact with other parts of the system.

Various livelihood activities including crop production, livestock husbandry, and off-farm activities happen simultaneously and interactively to complement or compete for farm resources. The common share in the mental models of the three discourses is the dynamics that lead to agroforestry adoption (balancing loop B1) and land allocation in the context of adoption (reinforcing loops R1, R2, R3) as well as impacts on soil erosion and household income. The number of causal links and their importance perceived by each discourse are the major differences.

For all discourses, severe soil erosion due to a long period of maize cultivation on slopes has led to the adoption of alternative cropping practices such as sugarcane cultivation

Table 2 Discourse characteristics. Median and mean (in parentheses) values are provided for age, land, and livestock.

Discourse	Gender (no. respondents)		Location (no. respondents)			Age	Land (ha)	Livestock (head)
	Male	Female	L1	L2	L3			
Discourse 1	10	4	1	4	9	54 (48)	1 (1.3)	3 (2.7)
Discourse 2	6	6	7	3	2	45 (44)	1.4 (1.7)	2.5 (3)
Discourse 3	2	6	1	5	2	43 (44)	1.3 (1.6)	1 (1.6)

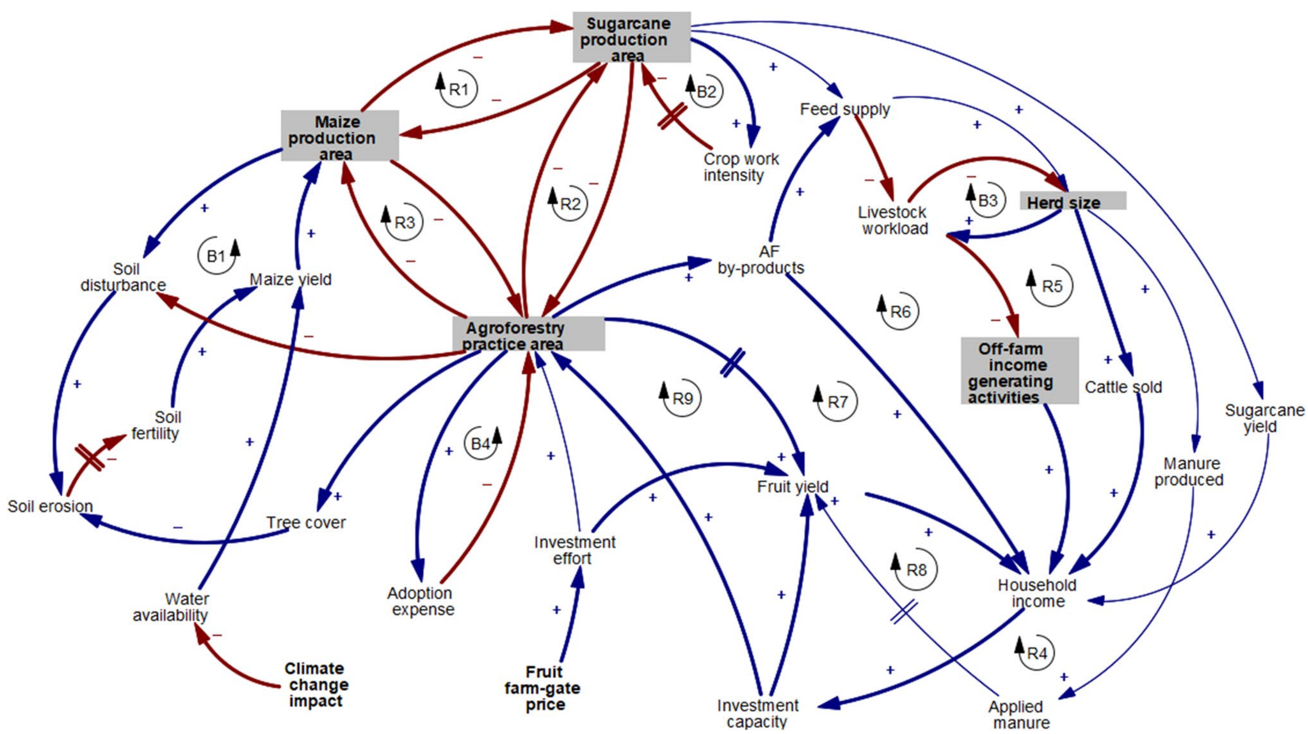


Fig. 6 Mental model of discourse 1. Blue arrows with "+" imply the same direction of change of two linked variables, whereas red arrows with "-" indicate a change in the opposite direction. Arrows with "||" indicate a delay in the impact between two variables. Bold arrows represent important links highlighted by the discourse. "R" indicates a reinforcing feedback loop with an even number of negative links. "B" represents a balancing feedback loop with an odd number of negative links.

or agroforestry. Sugarcane contributes significantly to the income of farmers in the study area. The contribution of sugarcane to household income is perceived as more important in discourse 2 (Fig. 7) and discourse 3 (Fig. 8) than in discourse 1 (Fig. 6). However, sugarcane requires high labor input experienced by all three discourses (balancing loop B2). The labor intensity of sugarcane production was emphasized by discourse 1 and discourse 3 who therefore expressed their desire to expand agroforestry area in the Q study. However, high adoption expenses (B4) and unstable farm-gate prices for fruit prevent them from expanding agroforestry on their land. Farmers reallocate land for different alternatives to secure their cash flow. This was considered an adoption strategy by all discourses. The adoption of agroforestry reduces soil erosion through reduced soil disturbance and increased soil cover due to the tree canopy. The practice also sustains feed supply for livestock production, and it diversifies income through intercropped products and fruits. High feed availability in agroforestry systems frees up labor for other income-generating activities. Farmers in discourse 1 and discourse 2 have increased their herd size, given sufficient feed supply from agroforestry, thereby raising their income through cattle sale. This dynamic may explain the higher number of cattle owed by discourse 1 and discourse 2 compared to discourse 3 (Table 2). The importance of these pathways, however, was perceived differently among discourses. Discourse 1 (Fig. 6) highlighted the importance of income diversification pathways through livestock, off-farm activities, and other agroforestry products besides fruit benefits while discourse 2 (Fig. 7) and discourse 3 (Fig. 8) rely on and expect more from fruits than from the other diversification pathways. This could be an explanation for

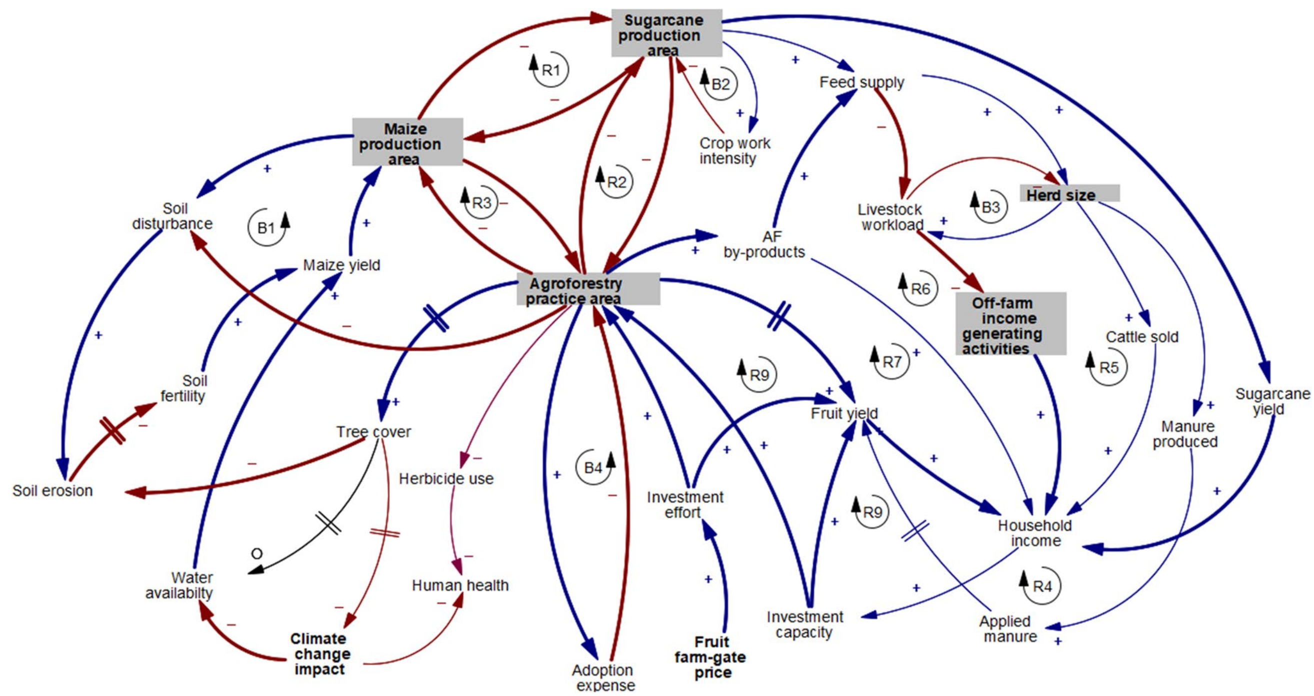


Fig. 7 Mental model of discourse 2. Blue arrows with "+" imply the same direction of change of two linked variables, whereas red arrows with "-" indicate a change in the opposite direction. Black arrows with "O" indicate an unclear relationship. Arrows with "||" indicate a delay in the impact between two variables. Bold arrows represent important links highlighted by the discourse. "R" indicates a reinforcing feedback loop with an even number of negative links. "B" represents a balancing feedback loop with an odd number of negative links.

the strong view held by farmers in these discourses on the statements regarding fruit yield and fruit price. The association between discourses and age and land area (Table 2) implies that older farmers and farmers with little land (discourse 1) tend to appreciate the diversification benefits of agroforestry. In addition to livelihood benefits, discourse 2 also mentioned other benefits from agroforestry, such as the reduction of herbicide use and effects of tree shade that have impacts on both climate and human health (Fig. 7). Discourse 1 and discourse 3 did not perceive such benefits.

3.4 Development pathway of agroforestry farmers

To provide a generalized and concrete story of the local farming system, we unified the three models by highlighting common and important interactions that are responsible for system behavior given the adoption of agroforestry (Fig. 9).

The balancing loop B1 presents an intervention point initiating changes in local land use. Expansion of maize monoculture over long periods is associated with frequent soil disturbance and loss of vegetative cover. This causes severe soil erosion problems. Depletion in soil fertility reduces maize yield substantially and thereby decreases household income. As maize yields decrease, farmers reduce the land area for maize cultivation to avoid losses. They re-allocate land to alternative crop settings such as sugarcane and tree-based systems. The new land-use configuration induces emergent behaviors by interacting with other elements within farms.

Sugarcane has played an important role in poverty reduction in recent years by increasing farm income. Given the expansion of the production scale of sugar manufacturing companies, which secures stable farm-gate prices, sugarcane remains dominant in terms of cultivated area and contribution to income generation in the region. Biomass from sugarcane also helps to sustain the feed supply for livestock production during the dry season. However, the production level for sugarcane is constrained by the intensive labor requirement of the practice, which forces many farmers to reduce production levels in the long run. This is partly due to the aging of those doing agricultural labor, illustrated by the balancing loop B2.

Farmers agreed that they adopted agroforestry as an intervention to reduce soil erosion and improve farm productivity. However, introducing this practice reduces the available area for maize and sugarcane production. This leads to a constraint on land resources, which is reflected in the negative reinforcing loops R1, R2, and R3 (Fig. 9). Tree-based systems incur costs for setting up tree stands (adoption expenses). Trees are expected to provide direct products (fruit yield) for income generation, which may allow re-investment

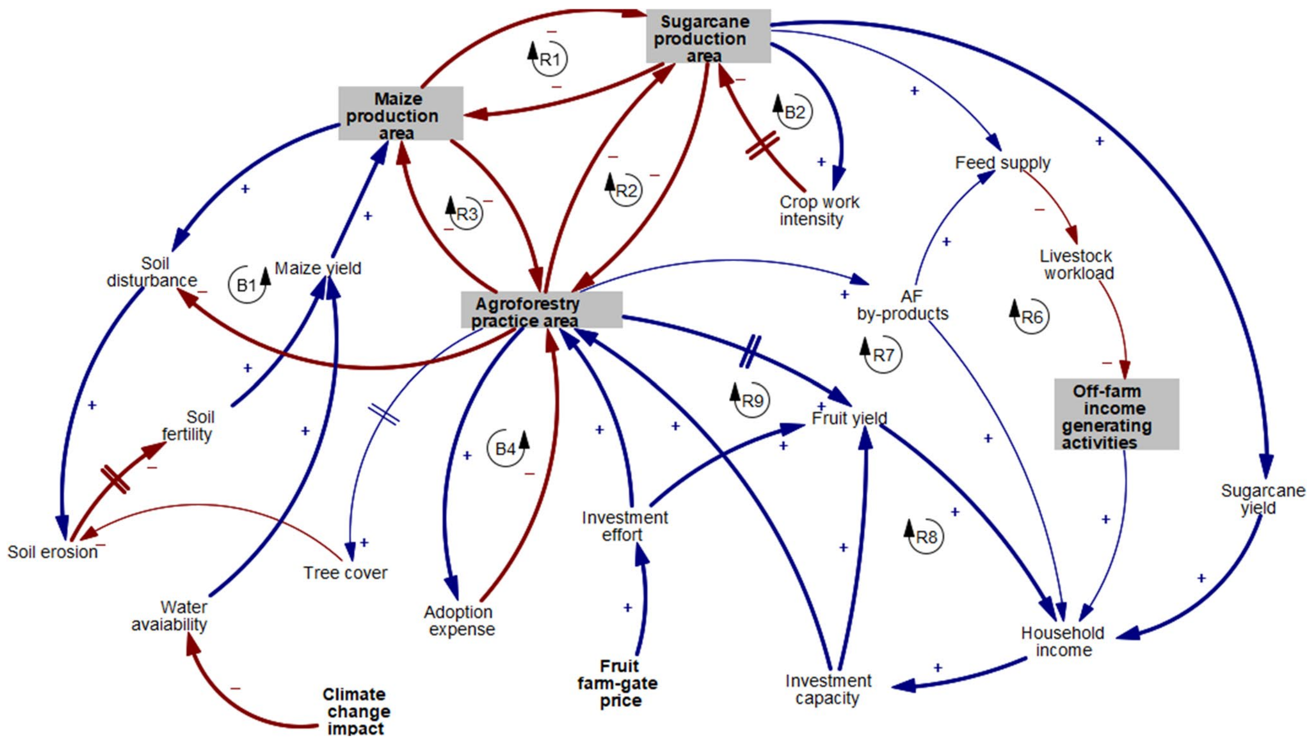


Fig. 8 Mental model of discourse 3. Blue arrows with "+" imply the same direction of change of two linked variables, whereas red arrows with "-" indicate a change in the opposite direction. Arrows with "||" indicate a delay in the impact between two variables. Bold arrows represent important links highlighted by the discourse. "R" indicates a reinforcing feedback loop with an even number of negative links. "B" represents a balancing feedback loop with an odd number of negative links.

in trees in order to enhance fruit yield or plant more trees (R7 and R8). This contribution is delayed, however, with a time lag until positive net returns from fruit trees are generated. The delayed impact makes the future behavior of agroforestry hard to predict. Without action, the reinforcing loops R2 and R3 might lock in farm operations given continuous investments without earnings for the first several years. In this case, full adoption may lead to system collapse. As a strategy, farmers may choose to transit slowly so that they can afford the adoption-related expenses (B4). Meanwhile, they create short-term income in various ways. These immediate incomes help enhance the investment capacity of farmers and allow them to further expand tree areas or improve tree productivity. This is demonstrated by the positive reinforcing loops R5, R6, and R7 (Fig. 9). Instead of a large-scale transition, farmers retain parts of their land distributed among other crops such as sugarcane, to maintain annual cash flows. In tree-covered land, they integrate annual and fodder crops to earn direct income (R7) and increase feed supply during the rainy season. The increase in feed availability reduces the time they spend on collecting fodder and herding cattle. With the additional free time, farmers get more housework done or participate in off-farm activities, which can add to household income (R6). On the other hand, given feed abundance, farmers tend to increase herd size, thus increasing the number of cattle available for breeding, household consumption and income generation (R5). Increasing herd size leads to higher manure availability for trees (Fig. 6 and Fig. 7) or for cash through sale to peers. The extension of livestock production is, however, constrained by labor availability, as illustrated by balancing loop B3. Instead of increasing herd size proportionately with the availability of fodder, farmers may balance the herd size at the level that they can manage with their household's labor resources.

Farmers perceived positive environmental impacts of agroforestry through enhanced soil cover with trees and other vegetation, which played a major role in reducing soil erosion. Participants also recognized several services contributed by trees, such as providing shade for farmers working in the field and dampening heat stress during hot days. In the long run, tree cover can alleviate the impact of climate extremes and conserve soil fertility through the reduction of soil erosion. Over longer periods, soil fertility builds up in agroforestry systems, which can then secure the yields of conventional crops. There is a chance for dis-adoption, where farmers abandon agroforestry and return to conventional crops (B6 and B5) given well-established markets for those crops. However, a long delay and lack of clarity on the impacts of tree-based systems on soil quality and the climate imply large uncertainty on this emergent behavior.

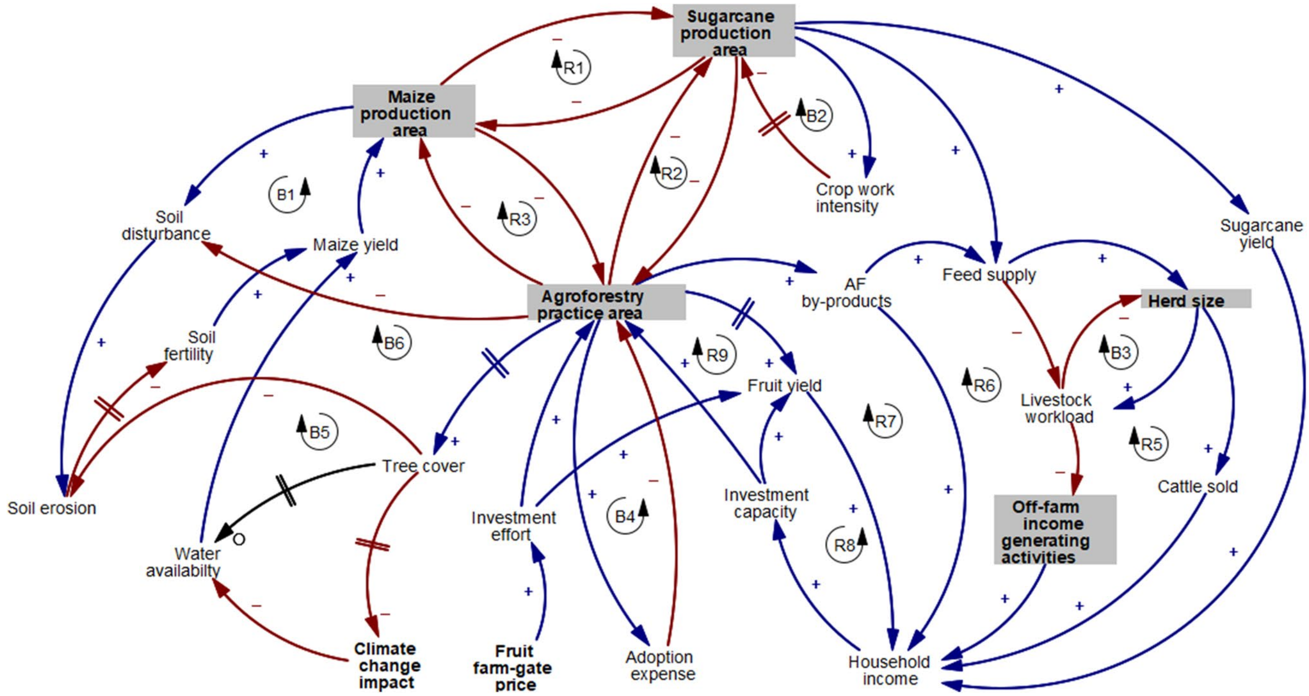


Fig. 9 Dominant feedback loops responsible for emergent behaviors within farming systems in the context of agroforestry adoption. Blue arrows with "+" imply the same direction of change of two linked variables, whereas red arrows with "-" indicate a change in the opposite direction. Black arrows with "O" indicate an unclear relationship. Arrows with "||" indicate a delay in the impact between two variables. "R" indicates a reinforcing feedback loop with an even number of negative links. "B" represents a balancing feedback loop with an odd number of negative links.

4 Discussion

We explored how farmers evaluated the use of agroforestry by analyzing their perceptions of the practice and its effects within their farming system. Through the application of the Q method, we extracted dominant discourses among local farmers focusing on the impacts of agroforestry. The systems thinking approach enabled learning and elicitation of a comprehensive understanding of farm management decisions through which adaptation strategies to overcome adoption challenges could be highlighted. Farmers acknowledged multiple benefits of agroforestry adoption. They navigated adoption challenges and found ways to overcome the challenges by drawing on their understanding of local farms and the farm environment.

Agroforestry has been favored by local farmers due to various positive impacts on the environment and on livelihoods. Reduction in soil erosion was mentioned by participants as one of the most beneficial environmental impacts of agroforestry. This implies that farmers who have experienced serious soil erosion and believe agroforestry could improve the situation are particularly likely to adopt the practice (Hoffman et al. 2014; Hastings et al. 2021). The underlying mechanism of the impact on soil was reflected in the Causal Loop Diagram generated in this study and also supported by plot-level experiments by Do et al. (2023). The authors reported a significant reduction in the amount of soil, soil organic carbon, and other soil nutrient elements that were eroded from fruit tree-based agroforestry systems compared to their monoculture counterparts. According to the Q study, farmers in our study area also perceived a reduction in labor input after adopting agroforestry. The result does not support the popular belief that agroforestry is more labor-intensive than monocropping (e.g., due to tree management operations and difficulties in the use of machines (Graves et al. 2017)), highlighting the importance of context. In monoculture settings of annual crops, labor demand is highly seasonal, especially at high cropping intensity, with peaks clustering around specific operations of sowing and harvesting (Kotir et al. 2022). The peaks constrain the area that can be managed by a unit of labor (Kotir et al. 2022). During the systems thinking session, farmers discussed that more types of crops can be managed in agroforestry than in monoculture given the same amount of time. They therefore believed that agroforestry has a higher labor productivity. This belief aligns with the findings of other studies that agroforestry had higher returns to labor (Ajayi et al. 2009; Armengot et al. 2016). Farmers also discussed the temporal distribution of agroforestry-related work over the year, which made farm work less intense, particularly for elderly farmers. This finding reflects a suggestion by Ajayi et al. (2009) for a modification to the agronomic management of agroforestry-based soil fertility management practices. They suggested shifting some of the labor inputs away from the main cropping season to the “off-peak” labor demand season, thereby enhancing acceptability among farmers when labor is limiting (Kotir et al. 2022). In addition, farmers elaborated further on the complementary effect of agroforestry (see discourse 1 and discourse 2 in Q method S7, Fig. 5). Fodder from agroforestry sustains livestock production and reduces labor needs for feed collection and herd supervision, freeing up time for other livelihood activities, which may have social implications (Kiptot and Franzel 2012) in addition to direct economic benefits.

We found that the most frequently mentioned challenges were related to high uncertainty about farm-gate prices and yields of fruits. The findings support previous work which emphasized the importance of these two factors in a prediction model of the economic performance of agroforestry in different settings (Do et al. 2020a). Our results show that the levels of uncertainty were perceived differently by farmer groups, distinguishing discourse 1 from discourses 2 and 3 (S9 & S23 in Fig. 5). The presence of reliable markets for alternative crops, in addition to bio-physical compatibility, is an important requirement when introducing farming practices that include new crop components (Roesch-McNally et al. 2018). Such markets are still missing in our study context. The absence of reliable markets increases farmers’ uncertainty about selling prices, which generally leads farmers to reduce the use of production inputs (Assouto et al. 2020). Farmers are reluctant to commit to investing in trees if they perceive high fluctuation in fruit prices (investment effort, Fig. 9). Cost control was employed by smallholder rice farmers in Tanzania as a strategy to guarantee their income margin in years with low market prices (Mgale and Yunxian 2021). Nevertheless, perennial fruit trees often demand unwavering investment (in terms of both plant nutrition and overall management effort) to ensure good yield performance in the long run (Carranca et al. 2018). Some farmers abandoned trees during 2 years of the COVID-19 pandemic when the market for fruits largely collapsed due to restricted transportation and lack of access to the Chinese market, the main market for fruits. Another challenge mentioned by discourse 3 in the Q study was that agroforestry requires a high level of investment. This has been highlighted in earlier research (Do et al. 2020a, b), which suggested financial incentives to promote adoption. However, the high complexity and diversity of agroforestry are causing many complications for policy-makers trying to develop a supporting framework for farmers who adopt the practice. Subsidies have been provided in the form of seedlings and fertilizers, but these measures were limited to short-term pilot projects. The private sector has taken part in providing tree seedlings and securing output markets for only a narrow range of tree species. Such profit-oriented activities by the private sector may encourage a spread of large-scale agroforestry that compromises the biodiversity-supporting nature of the practice. This may lead to a poor agroforestry transition, which may strengthen and institutionalize agribusiness practices that harm the environment and reduce social equity (Ollinaho and Kröger 2021).

Farmers often have little power to address structural challenges, such as uncertain farm-gate prices in this case, which may require interventions at higher levels, yet many have engaged in attempts to adapt and maintain system functions. Although financial incentives are highly appreciated, most farmers did not put a high weight on the need for incentives to adopt agroforestry (discourse 1 and discourse 2). During the systems thinking workshops, farmers rather focused on discussing how they have managed the adoption and overcome its challenges. To reduce the pressure from the high investment requirements of agroforestry, farmers implemented the transition at temporally and spatially slow rates. During the transition, they made use of the multiple benefits of the practice that were mentioned in the outcomes of systems thinking. The slow transition allowed for adaptive management of the adoption, minimizing the risk of failure given a range of uncertainties regarding the innovation (Klerkx et al. 2010). Such a gradual transition has been suggested as a means for making agroforestry feasible for resource-poor farmers (Do et al. 2020a). Farmers also maintained a diversity of crop settings across farm plots to enhance their ability to adapt to market and climate shocks. A diversified portfolio of crop production has proven to help spread risk and thus enhance the resilience of farming systems (Sulewski and Kłoczko-Gajewska 2014; Petersen-Rockney et al. 2021). Therefore, some farmers preferred allocating land for a diversity of crop settings to converting the whole farm to agroforestry. They were satisfied with having income spread over their land across the year.

For the majority of farmers in our study, spot markets where prices are decided at the time of selling were the dominant channel for fruit sales. In this arrangement, farmers usually rely on informal networks (farmer-to-farmer) to acquire market information such as price, buyers, or product standards. These networks equip them with bargaining power and reduce their uncertainty when making deals with buyers (Mgale and Yunxian 2021). For farmers living near local markets, self-retailing is also a common strategy whenever farmers disagree with the prices offered by regular traders. This strategy offers local women opportunities to participate in income-generating activities. Many women, during the discussion, reported additional income from the collection of fruits and other agricultural products on their land for sale on local markets. Some also diversify their product portfolio with prepared traditional food to earn additional cash and make the best use of their self-retailing time. Thereby, women can contribute to household income and possibly enhance their role in decision-making processes (Antman 2014; Arthur-Holmes and Abrefa Busia 2020). In some cases, forward-contracts are available, but this mainly applies to large fruit production farmers with intensive monoculture plantations, since such farmers can promise reliable supply. Small-scale agroforestry farmers may be able to ensure reliable supply by cooperating with their peers for pooling their capital resources and product outputs (Fernando et al. 2021). Farmer-driven cooperatives with good marketing strategies and service functions could eliminate the involvement of intermediaries in agroforestry supply chains and help improve farmers' returns from their products (Islam et al. 2018). Farmers in all three discourses considered cooperation as a key strategy to overcome structural market barriers. Farmers believed that by participating in farmer cooperatives, they could exchange knowledge and be provided with sufficient market information and potential involvement in certification schemes, thereby gaining access to and bargaining power in forward-contracts and securing a fair price. However, attempts to set up cooperatives are often unsuccessful due to cumbersome administrative procedures and a lack of business skills and trust among farmers. This may present a possible intervention point for the government, which may provide technical and financial assistance during the establishment and development of agricultural cooperatives. It is also essential for the government to stay engaged and maintain its authoritative role in examining and enhancing the capability of such cooperatives in their operational and decision-making management (Fernando et al. 2021). Engagement in other networks that include different stakeholders such as industry representatives, public agencies, and policymakers may also expand the options available to farmers and thereby reduce structural barriers (Roesch-McNally et al. 2018).

Farmer-to-farmer networks are common channels for farmers to exchange and disseminate technical knowledge. None of the discourses concerned technical issues of agroforestry (S6 and S16, Fig. 5), since farmers were able to access relevant and timely information from their peers. The association between location and farmer discourse in our analysis suggests an influence of social networks on farmer perceptions as an important driving factor of farmer actions. The location in our study represents both geographic proximity and similarity in farming style, experience, and cultural identity. These dimensions may be referred to as geographical proximity, cognitive proximity, and social proximity, as defined by Kabirigi et al. (2022), who reported significant relationships between the different forms of proximity and the likelihood that farmers share and ask other farmers for information. Our finding may have implications for interventions to integrate and promote informal networks in the existing formal extension system for effective knowledge exchange and social learning. However, formal research should be conducted on proximity aspects to provide nuanced recommendations within local contexts.

5 Conclusion

This study adds a new dimension to the assessment of agroforestry considering both consensus and disagreement in farmers' views on the practice within the whole-farm context. The benefits and challenges of agroforestry were perceived differently by farmer discourses in the Q study. There was, however, high consensus among the mental models elicited from the systems thinking reflecting similarity in farmers' adaptation strategies and expected impact pathways within local farms. Farmers leveraged the synergistic impacts of agroforestry on other farm components to overcome the challenges and better integrate agroforestry into the farm operation. It appeared that farmers think in systems, which highlights the importance of taking a whole-systems approach to assessing the implications of introducing new components into farm operations. The combination of the two research approaches offers a robust tool for agricultural development research, especially in the field of resource management where multiple stakeholder groups with conflicting interests and different expectations are often involved. The Q-method detects the characteristics and severity of conflicts between the views of different stakeholder groups on certain topics. Systems thinking then elucidates the dynamics explaining the different discourses, providing useful guidance for coordination and action.

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Authors' contributions Conceptualization, H.D., E.L., C.W., and N.L. Methodology, H.D. Investigation, H.D. and N.L.. Data analysis, H.D. Writing—original draft, H.D. Writing—review and editing, C.W., E.L., H.S., and N.L. Funding acquisition, H.D., E.L., N.L., H.S., and C.W. Supervision, E.L., C.W., N.L., and H.S.

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Data availability All generated or analyzed data is included in the Supplementary.

Declarations

Ethics approval This research was conducted according to the ICRAF's Policy Guidelines on Research Ethics 2014 and its later amendments.

Consent to participate Informed consent was obtained prior to the interview, Q study, and workshops.

Consent for publication The authors confirm that all the participants provided informed consent to participate in the study and agreed on a publication of the results.

Conflict of interest The authors declare no competing interests.

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