Wageningen University - FSE80436
June 2023
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Silvopasture for improved smallholder crop-livestock systems: a case study of sustainable intensification in the Xieng Khouang province, Lao PDR

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Abstract

Rapid changes in the regional economy and livelihoods of smallholder farmers in South-East Asia, driven by agricultural commercialization, have led to increased cash incomes and economic growth but have also raised concerns about environmental impacts. These developments pose a threat to the ecosystem and food security of smallholder farmers in the Lao People's Democratic Republic (Laos). The objective is to identify strategies that enable smallholder farmers to benefit from commercialization while ensuring sustainable agricultural practices and livelihoods. Silvopastoral systems integrate trees, forage crops and livestock and has the potential to sustainably intensify smallholder mixed farming. This study aims to evaluate the potential of silvopastoral designs for smallholder crop-livestock farmers in the Lao uplands.

The research takes a holistic approach, considering various dimensions of sustainable intensification. Livelihood trajectory analysis and surveys were conducted with 18 farmers from different villages to understand the changes in farmers' livelihoods over time and quantify inputs, outputs, and resource flows. Two silvopastoral systems were designed, incorporating different tree species, and their effects on socio-economic and environmental indicators were assessed using the FarmDESIGN model. Additionally, focus group discussions were held to gather farmers' perspectives on implementing silvopastoral systems.

The findings indicate that livelihoods in the region have become more diversified and market-oriented. However, their growing dependence on export-oriented production presents a significant risk to the soil fertility due to depletion of nutrients. The modelling analysis suggests that adopting silvopastoral systems can lead to increased gross margins of animal husbandry and available household budgets, reduced costs and labour requirements, and positive environmental impacts, depending on the type of tree integrated into the system. However, constraints for the implementation by farmers are financial resources, labour shortage and a lack of knowledge.

Considering the interplay of factors such as negative nitrogen balances, farmers' concerns about crop productivity, government prioritization of the livestock sector, and growing farmer interest in livestock, the need to establish a sustainable intensification pathway becomes paramount. This study underscores the importance of employing a holistic system approach that incorporates mixed methods and indicators from diverse disciplinary dimensions in agricultural research, enhancing understanding of the externalities and consequences associated with the adoption of sustainable intensification strategies.

Keywords: *Agricultural commercialization, FarmDESIGN, Laos, Livelihood trajectory analysis, Livestock management, Sustainable intensification.*

Abbreviations: *Dry matter (DM), Focus Group Discussions (FGDs), Nitrogen (N), National Agriculture and Forestry Research Institute (NAFRI), Organic Matter (OM) Rural Household Multi-Indicator Survey (RHoMIS), Sustainable Intensification (SI), Silvopastoral Systems (SPS), Sustainable Intensification Assessment Framework (SIAF), Total Digestible Nutrients (TDN).*

1. Introduction

1.1 Context

The Lao People's Democratic Republic (Laos) is a landlocked country located in the heart of the Greater Mekong Subregion that currently faces rapid changes in the regional economy, livelihoods and farming systems. Laos has the smallest total population size of the region, of which around 80% is still dependent on agriculture for subsistence (FAO, 2022). Improved infrastructure increased the market access to neighbouring countries and made former remote communities connected to the global supply chains (Napasirth & Napasirth, 2018). As a result, farmers' incomes increased which reduced the poverty rate from 46% in 1993 to 18.3% in 2019[1] (World Bank Group, 2020). The livestock sector is one of the fastest growing agricultural sectors in the country (Napasirth & Napasirth, 2018), driven by a growing demand for livestock products due to increased incomes and urbanization. This trend has been further strengthened since 2021 by a government campaign to boost the cattle exports to China (Xinhua, 2021). Simultaneously, there is a surge in cash crops such as maize for animal feed to meet the growing demand in the Vietnamese market (Cole, 2022), while the tea sector is undergoing development to cater to the Chinese market (Phouyyavong et al., 2018). These developments align with policy objectives that aim to transition from traditional swidden cultivation to market-driven production through intensive agricultural methods (Alexander et al., 2010; Castella et al., 2013, 2018).

1.2 Challenge

Although the commercialization of farming systems has led to an increase in cash incomes, economic growth, and export revenue (Cole, 2022; Phouyyavong et al., 2018), it has also resulted in numerous adverse impacts on the environment (Rietveld et al., 2021). The use of agrochemicals, the reduction of fallow plots in rotations and impacts of climate change have already resulted into soil degradation, erosion, poor harvests and a loss of biodiversity as the traditional fertility management techniques are no longer possible (Castella et al., 2013; Epper et al., 2020; Kallio et al., 2019; Paul et al., 2022). These developments pose a threat to the long-term sustainability and resilience of the ecosystem, food insufficiency and malnutrition levels. And also on a socio-economic level is this a challenging transition, as farmers are dealing with a scarcity of labour and high opportunity costs to enter these opportunities (Manivong et al., 2014). The challenge lies in enabling smallholder farmers to benefit from the market opportunities while ensuring that the demands of the rapid changes in the economy can be met with sustainable intensified agricultural systems and livelihoods.

1.3 What's known

The potential for mitigating the negative consequences of these developments in Laos can be found in the concept of sustainable intensification (SI) within mixed systems. This approach aims to increase food production on existing land while minimizing adverse environmental impacts (Zurek et al., 2015). By integrating livestock with crop production and managing them well within a silvopastoral system (SPS), it is possible to address the economic-environmental trade-offs. This can be achieved by converting crop residues into animal feed and utilizing manure as a fertiliser (Paul et al., 2022). SPS combines trees, forage and livestock components on the same plot of land (Cubbage et al., 2012). Due to the many interactions between these components with the landscape, it requires more complex and intensive management but also creates greater opportunities. SPS could reduce pasture degradation, increase soil carbon and enhance nutrient cycling, water retention properties and biodiversity (Sauer et al., 2021). It also plays a role in climate mitigation through landscape carbon sequestration (Devendra, 2012; Montagnini et al., 2013). Besides, the trees can provide fodder and their shade can protect cattle from environmental stressors that might reduce animal production (Pent, 2020). However, shade and the competition for water can reduce the forage yield but may

[1] Poverty headcount ratio at national poverty lines (% of population)

increase the forage quality and longevity compared to open pastures (Kallenbach et al., 2006). For the farmers, the adoption of SPS can lead to increased food security (Choocharoen et al., 2014), secure livelihoods and more diverse income sources (Rahman et al., 2017; van der Meer Simo et al., 2020). This is however dependent on institutional aspects of land ownership and market access (van der Meer Simo et al., 2020).

1.4 Knowledge gap

Scientific research on SPS in low-input land-use systems is generally insufficient and often focused on specific disciplines, as highlighted by Nair et al. (2021). There is a lack of comprehensive studies that adequately represent SPS in these contexts. By focusing on Laos as a research area, this study aims to contribute to closing the research gap on SPS in the Asia-Pacific region (Shin et al., 2020). The quantification of the impact of SPS on the livelihoods of Lao farmers represents a knowledge gap that is crucial to address for the formulation of effective policies that promote SI (Choocharoen et al., 2014; Van Der Meer Simo et al., 2018; van der Meer Simo et al., 2020). Incorporating a systems perspective that encompasses the social dimension can enhance the understanding of the externalities and consequences associated with changes related to other dimensions (Rietveld et al., 2021). Furthermore, the limited research conducted on sustainable production systems in the context of Laos has resulted in a lack of knowledge among policymakers and farmers regarding the selection and utilization of suitable tree species within potential SPS designs[2].

1.5 Research objectives

Hence, the objective of this study was to investigate the potential of silvopasture in promoting SI of smallholder crop-livestock systems in the Xieng Khouang province, Laos. This comprehensive research involves multiple subsidiary objectives:

i. Examining the trajectories of farmers' livelihoods over time, particularly in relation to the trend of agricultural intensification.
ii. Identifying and evaluating possible silvopastoral designs with different integrated tree species.
iii. Quantifying the inputs, outputs, and resource flows within the selected SPS designs and assessing their socio-economic and environmental impacts through farm modelling.
iv. Investigating farmers' perspectives and willingness to adopt SPS as potential users.

By adopting this holistic approach, the study aims to provide a thorough understanding of the potential benefits, challenges, and feasibility of implementing silvopasture as a SI strategy in smallholder crop-livestock systems in the Xieng Khouang province.

[2] Personal communication with CIAT & NAFRI, 2023

2. Methodology

2.1 Site description and farming systems

This research is part of the Sustainable Intensification of Mixed Farming Systems (SI-MFS) initiative of the CGIAR that aims to 'provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socioeconomic settings' (CGIAR, n.d.). The uplands of Laos have been selected as one of the focus areas from which global relevance will be shared.

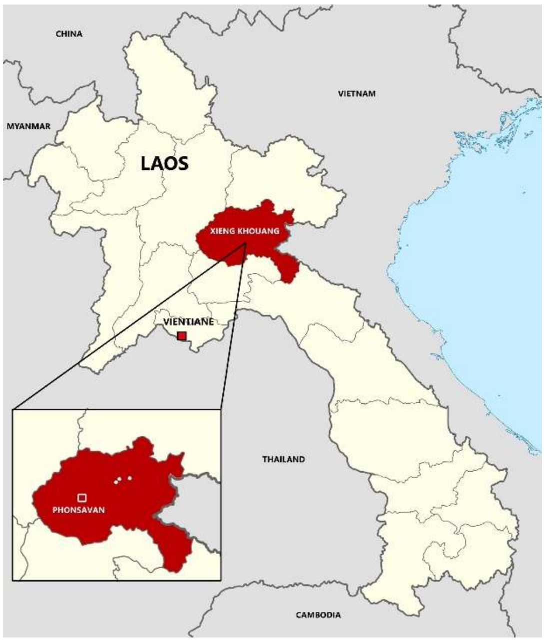

Figure 1
Map of Lao People's Democratic Republic (Laos) with the province Xieng Khouang highlighted in red. The box on the left provides a detail of the Xieng Khouang province with the capital Phonsavan, and the three case study villages (from left to right) Tar, Or Anh and Pa Khom.

The study was conducted in the Pek district in the Xieng Khouang province (Lao: ຊຽງຂວາງ, meaning 'Horizontal City'), in the Northeast of Laos (Figure 1). It is characterized by highland extensive mixed systems, with small inputs of fertiliser and labour. The smallholder crop-livestock farmers are mostly subsistence oriented and swidden practices remain commonly used (FAO et al., 2022). Pek has the highest number of livestock and lowest poverty rate compared to the other districts in the province (LURAS, 2022). Upcoming developments are cattle fattening, forage production (*Brachiaria ruziziensis*) and the cultivation of maize (Paul et al., 2022). The province is one of the most intensely bombed areas per capita in history by the U.S. bombing missions as part of the Secret war during the Vietnam War (1964-1973). Hence, the bombing missions have a persistent negative impact on the long-term economic outcomes in the province (Yamada & Yamada, 2021).

2.2 Farm selection

In order to study livelihood trajectories, the same villages as previous studies by Epper et al. (2020) and Ritzema et al. (2019) were selected: *Tar, Pa Khom* and *Or Anh*. To characterize farming systems, data from the Rural Household Multi-Indicator Survey (RHoMIS) of Ritzema et al. (2019) was utilized. This dataset was collected in 2015 and consists of information from 366 households in Xieng Khouang. The livelihood trajectory of the households in this dataset are characterized by varying degrees of diversity (Equation 1) and market orientation (Equation 2). The level of market orientation illustrates the relative significance of crop and livestock sales in generating the potential food energy that is available for the household.

$$Cumulative\ diversity = Number\ of\ livestock\ species + Number\ of\ crops \quad (1)$$

$$Market\ orientation = \frac{\frac{Total\ farm\ income\ [\$]}{Staple\ crop\ price\ [\frac{\$}{kg}]} * Staple\ crop\ energy\ [\frac{kcal}{kg}]}{Total\ energy\ available\ [kcal]} \quad (2)$$

The use of these variables allows to identify different farm types present in the villages. The farm types can be described as:

A. High diversity (> 8), high level of market orientation (> 0.5);
B. High diversity (> 8), low level of market orientation (< 0.1);
C. Low diversity (< 5), low level of market orientation (< 0.1);
D. Low diversity (< 5), high level of market orientation (> 0.5).

The RHoMIS households were categorized into the different farm types within the three villages (Figure 2). The farms that were assigned to a farm type were approached by their village head to participate in the study. Although not every farm type was present in every village, an equal distribution was followed as far as possible.

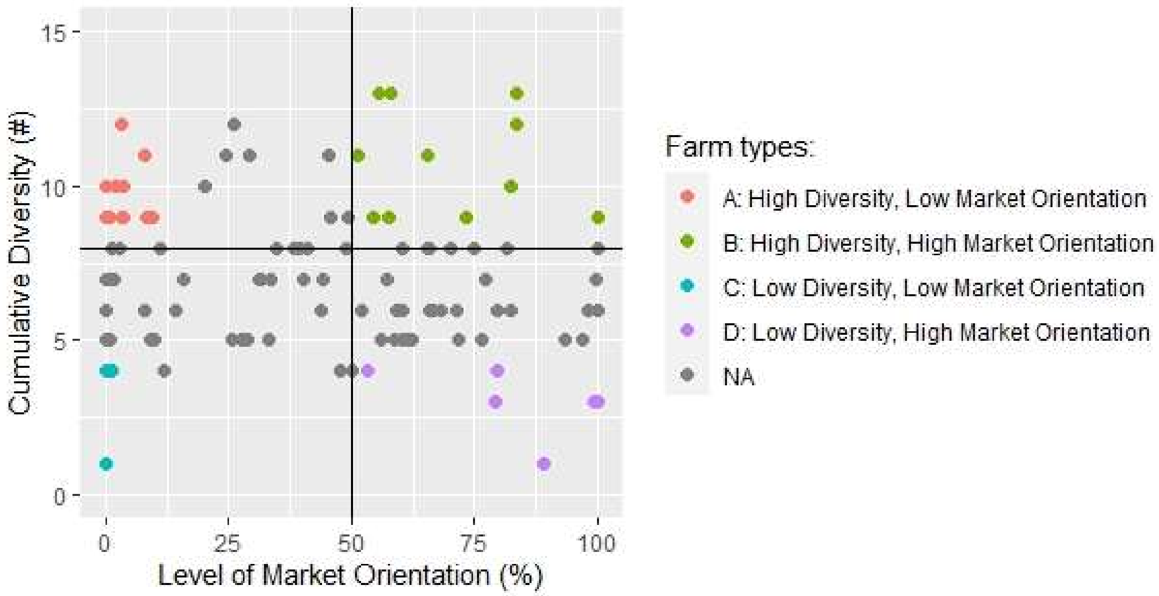

Figure 2

Overview of the farms in Tar, Pa Khom and Or Anh in the RHoMIS dataset plotted against the level of market orientation and cumulative diversity. The coloured dots represent farms that are assigned to specific farm types (A/B/C/D), whereas the grey farms do not fall under any farm type and have therefore not been included in the research.

2.3 Data collection

The data collection process for this study involved multiple steps that were carried out with 18 farms in three villages (Table 1). During the first fieldwork, a visit was made to the farms. During this visit, the layout and practices of the farmers were observed, potential SPS in the village were identified, and a structured survey was conducted with the farmers (§2.3.1). The data obtained from this survey was used for two purposes: firstly, for conducting a livelihood trajectory analysis by comparing the RHoMIS data from 2015 with the survey data (§2.4.1); and secondly, as input for the FarmDESIGN modelling to examine the farm performance in the current situation and compare it with hypothetical SPS scenarios (§2.4.2). In a subsequent fieldwork, focus group discussions (FGDs) were organized with the same farmers as the survey respondents (§2.3.2).

2.3.1 Survey and farm visits

A survey was used to collect both quantitative farm data and qualitative information regarding a hypothetical SPS, as well as past changes, concerns and future plans of the respondents (Appendix A). A total of 18 Hmong respondents were interviewed in February 2023 together with a translator and a district deputy. The latter sometimes also served as a second translator when respondents only spoke the local Hmong language. The surveys were combined with a visit to the farm, where qualitative insights into various forms of mixed farming and the presence or absence of SPS were obtained through observation. Notes and photos were taken to document these findings.

Table 1.

Village characteristics of the research area Tar, Or Anh and Pa Khom. Data obtained from the village heads.

Village	Farm type	Population	Households	Male - Female	Village area	Forest area
	A / B / C / D	*#*	*#*	*#*	*Hectares*	*Hectares*
Tar	2 / 0 / 2 / 0	331	44	161-170	14,622	14,523
Or Anh	2 / 2 / 1 / 1	374	60	194 -180	1,832	831
Pa Khom	1 / 3 / 1 / 3	562	85	333 - 229	1,200	15

2.3.2 Focus Group Discussions

FGDs are helpful in the elicitation of a wide variety of different views as participants are challenged to engage in arguing with other participants (Bryman, 2016). The objective of conducting FGDs in this study was to explore the willingness of the farmers to adopt silvopastoral elements on their farms and gather their opinions on SPS designs and their potential effects on farm performance. The previously surveyed farmers and the village heads have been invited to participate in a FGD in their village in April 2023. A total of 13 respondents took part in 3 separate FGDs. The discussions were moderated together with a translator and district deputy. Topics included livestock, erosion and the silvopastoral designs (Appendix D). For example, farmers desire to expand their cattle herd, their perception of soil erosion as a problem, and challenges and advantages of implementing a SPS on their farm. Before answering the questions, efforts were made to ensure that each respondent understood the subject with the help of printed examples (Appendix E). To link the FGDs data with the survey data, each farmer was assigned a visible number. Farmers used their number to answer Likert scale questions, by placing their number on a 1 – 10 scale poster. The benefits of the tree species and expected challenges were collectively ranked by the participants, aided by visualisations that included pictures with Lao subtitling (Appendix E). Raising hands was used to indicate agreement or disagreement with closed questions and to represent an 'increase' in either yield, soil fertility, costs or labour in the proposed SPS. As the group of respondents was small, open questions were answered individually while inviting other respondents to react.

2.4 Data analysis

2.4.1 Livelihood trajectories

A comparison was made between the farm situation of 2015 utilizing the RHoMIS dataset (Ritzema et al., 2019) and the 2023 situation based on the survey data. Six indicators, which represent different aspects of the farm situation, were used to identify livelihood trajectories. To assess the changes over time, a linear regression analysis was performed. This aimed to determine the average value of each indicator and its relative change for every village and farm type. In addition to this quantitative analysis, the open questions of the survey provided qualitative insights into the changes, concerns and future ideas of the farmers, contributing to a comprehensive understanding of their livelihood trajectories.

2.4.2 FarmDESIGN

The whole-farm model FarmDESIGN supports the evaluation and re-design of mixed farming systems, following the Describe – Explain – Evaluate - Explore – Design cycle based on Giller et al. (2008). This model has the potential to describe the farming systems and livelihoods, identify trade-offs and synergies and provide ex-ante assessments of the integration of silvopastoral components (Groot et al., 2012).

At first, a repository farm model was created to function as a basic model to efficiently customize the case study farm designs. The crops and livestock in this design were parameterized using the dataset of Epper et al. (2020), with additional or unknown parameters sourced from literature or existing datasets available through FarmDESIGN[3]. Consequently, the creation of this model served as a repository of data, enabling to fill in missing data gaps in the collected survey data.

Secondly, averages were derived from the individual survey farm data collected in each village to configure a representation of a single mixed-farming system in Tar, Or Anh and Pa Khom. This configuration served as input for the *Describe* phase. These three initial designs of each village's farm were adapted to an optimized starting point design, referred to as the baseline. This baseline design aimed to achieve more balanced feed requirements, including structural material (fibre), crude protein, metabolizable energy and dry matter intake capacity.

Subsequently, a copy of the baseline designs that incorporated a tree species in the *B. ruziziensis* pasture was created. Two different SPS scenarios were configured for each village in the FarmDESIGN model, representing distinct SPS designs. The SPS-related factors such as pasture yield, costs, labour and animal production were determined based on expert knowledge and literature. Ultimately, these steps facilitated the analysis of the effects of integrating a SPS on farm performance, allowing for comparisons across the three villages and between tree species.

In the *Explain* phase, the farm performance of each design was evaluated using the Sustainable Intensification Assessment Framework (SIAF) developed by Musumba et al. (2017). This framework includes objective-oriented SI indicators organized in five sustainability domains. Based on the data collection and literature review, eight indicators within the economic and environmental domains were selected for the *Evaluate* phase (Table 2).

The final two phases of the cycle were deemed unnecessary for implementation in this study.

[3] Feedipedia, USDA databases

Table 2

Farm performance indicators within FarmDESIGN, based on the SI domains of SIAF (Musumba et al., 2017).

SI Domain	*Indicator*
Economic	Maximize **the gross margin of animals and crops**, to achieve a higher profitability of the farm. Maximize a **free budget** as a financial result. A surplus credit allows the farm to invest and not only produce for subsistence. The **total farm costs** should be minimized. Constraints: The **regular labour requirement** of adapting and managing a SPS should not exceed the total availability of labour hours. The **off-farm labour** should not exceed the available labour hours.
Environment	Maximize the **soil organic matter balance**, thereby enhancing inherent soil fertility and water retention. Maximize the **nitrogen balance**, as previous research in the Pek district showed that irrespective of the orientation of the farm in the Pek district, soil nutrient stocks are mined and soil fertility is declining (Epper et al., 2020). Constraints: Livestock maintenance of the grazing animals (cattle and buffalo) must be guaranteed in respect to **feeding requirements** of dry matter (≤ 100% of saturation), metabolizable energy (95-105%), protein (100-130%) and structure (> 100%) intake. Including the optimization of crop residues utilisation as animal feed for an improved feed balance.

2.5 Silvopastoral system design

2.5.1 Current silvopastoral designs

One of the objectives of this study was to identify and evaluate possible silvopastoral designs with different integrated trees. During visits to the villages, consciously designed existing SPS were not observed. However, natural occurrences of SPS were noticed, such as when free-grazing cattle grazed in wild tea plots, at the edges of forest-farmland or in strips of planted trees (Figure 3-a). The surrounding natural forests in all villages provided opportunities for the occurrence of these systems. Both district and provincial deputies acknowledged the presence of such systems in their respective areas, and the Department of Agriculture and Forestry (DAFO) supports farmers to establish SPS by providing technical knowledge[4].

a) *b)*

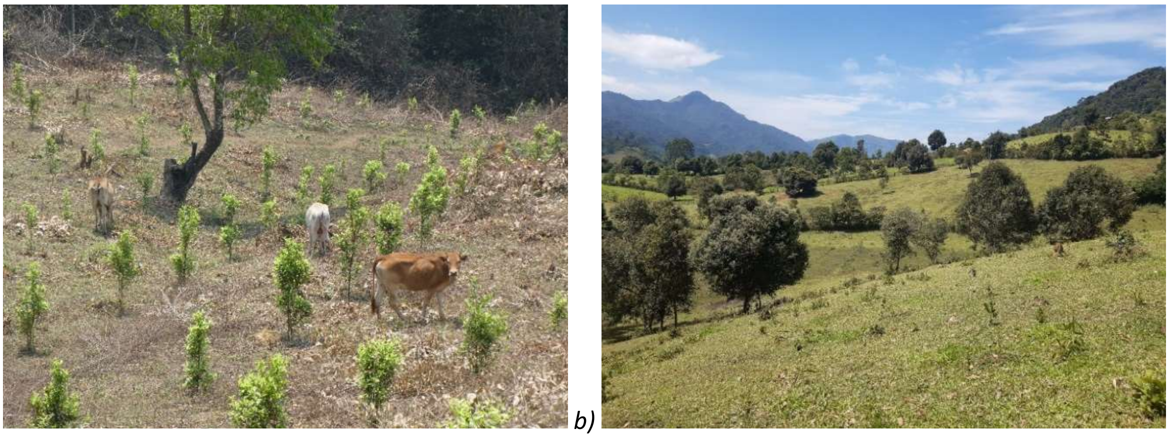

Figure 3

a) Cattle grazing in presumably young citrus trees, close to Pa Khom village (source: own picture). b) Living fence system in Xieng Khouang province, including Castanopsis Hystrix (source: NAFRI).

Phouyyavong et al. (2019) identified five cattle grazing systems in the uplands of Northern Laos, which included rotations of free-ranging in fallow fields, grazing in fenced fallow fields, rotation grazing, and cut-and-carry systems. Additionally, the Head of Forest Economics and Technology at the National Agriculture and Forestry Research Institute (NAFRI)[5] encountered SPS designed as 'living fences', where farmers preserved or planted trees along their plot boundaries to serve as poles for fence-lines (Figure 3-b) (Nair et al., 2021). Other observed systems included rows of trees and scattered trees. In most cases, the focus is on the preservation of trees that naturally spread from the surrounding forests, as plant nurseries are not commonly available. According to DAFO[4], farmers adopted living fence systems because, compared to the more common practice of a free-grazing system, keeping cattle on the same pasture with tree fences saved time in searching for the cattle, facilitated disease recognition, and allowed for a cut-and-carry system. Moreover, as the population is increasing, the risk of being held liable for damages caused by your cattle on someone else's land is becoming a concern. These aspects are all increasingly important now that the focus of many farmers has shifted to selling cattle rather than keeping them solely for household consumption.

2.5.2 Tree selection

During the surveys, respondents expressed a particular interest in planting fruit trees like mango, orange and jackfruit because of their dual purpose for both home consumption and the market.

[4] Personal communication, 28/03/2023, Phonsavan
[5] Personal communication, 02/03/2023, Vientiane

However, considering the risk of tree damage caused by cattle, which may adversely affect fruit production (Yagasaki, 2022), it was decided in consultation with experts that fruit trees might not be the most suitable option for the SPS designs in this context. Nevertheless, there could be potential in implementing a cut-and-carry system involving fruit trees with *B. ruziziensis* (Cheva-Isarakul, 1990), this is however not the focus of this study.

A preselection process was conducted based on a survey of tree species in mixed farming systems in Xieng Khouang province carried out by the NAFRI (Vongkhamho et al., 2022). Subsequently, in accordance with local experts, five categories of decision criteria were used to select two tree species suitable for inclusion in a SPS (Table 3). These selected tree species have been parameterized in FarmDESIGN to explore the potential contribution of SPS in the three villages.

Table 3

The decision criteria for the selection of tree species in the SPS designs and the features of the two selected tree species.

Tree species	*N-Fixation*	*Fodder*	*Origin*	*Purposes*	*Erosion control*
Leucaena leucocephala (Mak Ka Thin)	150 *kg ha⁻¹ y⁻¹* [i]	High biomass potential of high protein and palatable fodder for ruminants* [ii]	Native to tropical America but cultivated and naturalised in Laos [iii]	Rapid growth[iv] Human consumption of leaves, flowers and beans [iii] Of cultural importance to the local Hmong people [iii] Used as medicine [iii] Wood, charcoal and paper-pulp [v]	Stress-tolerant: deep taproot that helps to avoid erosion and beneficial for drought-tolerance [ii]
Castanopsis hystrix (Mak kor Daeng)	-	Leaves can be used as fodder [vi]	Wide variety of *Castanopsis* occurrence in the Northern Highlands of Laos[vii viii]	Human consumption of seeds [ix] Timber and firewood [ix] Good carbon sequestration capacity [x] Symbiosis with *Hed Kor Daeng* mushrooms[xi], for home consumption or market. Branches can also be used for mushroom cultivation [ix]	Shallow root system [xii], used in designs against soil erosion [viii]

**The use of fodder is limited due to non-protein amino acid mimosine that is toxic to animals. Therefore, it must always be fed in combination with grasses* (Halliday et al., 2013).

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[i] (Shelton et al., 2021)
[ii] (Qamar et al., 2015)
[iii] (Pha Tad Ke Botanica Garden, n.d.)
[iv] (Gill et al., 2020)
[v] (Cook et al., 2020)
[vi] (Prasad Pokharel et al., 2021)
[vii] (Cheuk & Fischer, 2021)
[viii] (Yagasaki, 2022)
[ix] (Bounthammy, 2019)
[x] (Shen et al., 2023)
[xi] (Foppes & Xayalath, 2022)
[xii] (Wang et al., 2022)

3. Results

3.1 Livelihood trajectories

In the time period from 2015 to 2023, the three villages underwent similar developments, as outlined in Table 4. The cumulative diversity within the villages increased, surpassing a level of 8, primarily due to the growth in livestock holdings. The land area cultivated per farm in each village more than doubled on average, with the village of Tar experiencing a particularly notable increase from an average of 1 hectare in 2015 to 7.28 hectares in 2023. Total farm income witnessed a substantial rise, while household sizes decreased.

An examination of different farm types also reveals certain relationships (Table B1). Diversified farm types (A and B) displayed a decrease in cumulative diversity, although it remained above 8. On the other hand, C and D, which initially had low diversity in 2015, experienced an increase (>80%) in their cumulative diversity. In 2023, farms with high diversity (A and B) had fewer household members compared to 2015, while farms with low diversity (C and D) saw a slight increase in household size.

Table 4

Livelihood characteristics of the 18 farms in the villages, comparing 2015 based on a RHoMIS dataset (Ritzema et al., 2019) *with the collected survey data in 2023.*

Village	Year	Cumulative diversity	Market Orientation	Household Size	Land cultivated	Livestock holdings	Total Farm income
		#	*%*	*Persons*	*Hectares*	*TLU*	*USD y^{-1} ***
Tar	2015	6.8	1.30	7.00	1.00	6.54	92.28
	2023	8.3	-	6.25	7.28	10.27	4,538.50*
Or Anh	2015	7.7	39.41	7.00	3.20	3.44	4,537.26
	2023	8.0	-	5.67	10.31	7.33*	7,801.00*
Pa Khom	2015	7.4	58.67	6.75	3.29	4.37	1,325.84
	2023	8.6*	-	6.38*	8.20	9.66*	2,755.00*

**Significant change between 2015 and 2023 (p-value ≤ 0.05).*
***The total farm income derived from the RHoMIS 2015 dataset have been converted to the 2023 USD ($) exchange rate.*

All farmers reported in the survey that they experienced a large improvement of their livelihoods over the past 10-15 years. Farmers changed from mainly producing for subsistence, being poor and performing the traditional practice of slash-and-burn to focusing more on producing for the markets. In the villages Tar and Or Anh, the introduction of the Phou San tea market played an essential role in boosting household budgets, enabling farmers to purchase vehicles, improve their houses, and acquire more land and cattle. Many farmers have established their own tea businesses, catering to the Chinese market. Similarly, in Pa Khom, banana and maize cultivation, which was previously limited to subsistence, experienced a transformation with the entry of the Vietnamese companies into the area. It provided farmers with market opportunities to sell their produce, leading to an improvement in their livelihoods. Farmers also noted how the villages themselves improved with better roads and the construction of an electricity grid.

However, tea-producing farmers expressed concerns about market prices, as more farmers enter the tea production by establishing their own plantations. This influx of farmers is partly driven by the growing village population. Additionally, farmers strongly valued their independence, seeking to avoid government interference and preferring to conduct sales without intermediaries.

In Pa Khom, farmers were facing a decline in their maize yield due to soil degradation. While fertilising the plots was seen as a solution, farmers lacked the necessary knowledge and were reluctant as the extra costs would affect the gross margin of their maize production. As a result of this concern, farmers were shifting their focus to banana and orange trees, as well as expanding pastureland for cattle, as a means of ensuring their future security.

3.2 Whole-farm modelling

The surveyed mixed farming systems have undergone a redesign and evaluation in the whole-farm model FarmDESIGN (Table 5). For each village, two scenarios have been developed: one SPS incorporating *L. leucocephala*, and another scenario with *C. hystrix* (Table 3). The farm performance of these redesigned farming systems is assessed using economic and environmental indicators.

Table 5

Overview of the farm characteristics per village, based on the averages of the survey data per village. This served as the input for the baseline scenario in the FarmDESIGN model and the exploration of the SPS scenarios.

	Area [ha]	*Crops*	*Livestock**	*Casual Labour*	*Off-farm labour*
Tar	6.96	Rice paddy B. ruziziensis pasture Phou San Tea Cassava Vegetable garden***	Cattle (8) Cattle Young** (3) Pig (1) Chicken (21) Duck (15)	No	Yes
Or Anh	9.66	Rice paddy B. ruziziensis pasture Phou San Tea Vegetable garden***	Cattle (4) Cattle Young** (3) Buffalo (8) Chicken (16) Duck (9)	Yes, on Tea plot	No
Pa Khom	8.25	Rice paddy B. ruziziensis pasture Maize Banana Vegetable garden***	Cattle (8) Cattle young** (8) Pig (4) Fighting Bull (1) Chicken (24) Duck (15)	Yes, on Maize plot	No

**The number between brackets represents the number of animals on the farm.*
*** Young cattle are defined as <3 years of age.*
**** The different crops in the vegetable garden are not listed individually but are grouped together.*

3.2.1 Economic domain

In all SPS scenarios, the gross margin of animal husbandry showed an increase, while the gross margin of the crop products decreased by only 4-6%. Overall, all scenarios yielded positive economic outcomes (Figure 4). The available budget would increase for the household, partly driven by the decline in farm costs. Integrating *C. hystrix* in Tar, for instance, resulted in a yearly total farm costs of 5,877 USD instead of 7,291 USD (Table 6). This decline results from the long-term investment in trees used as living fences, which eliminates the costs for annual hole digging and fence replacement. Besides, the SPS systems would require less regular labour and provide more leisure time. For example, the regular labour balance in a *L. leucocephala* scenario in Or Anh would change from 746 hours y^{-1} to 1128 hours y^{-1}.

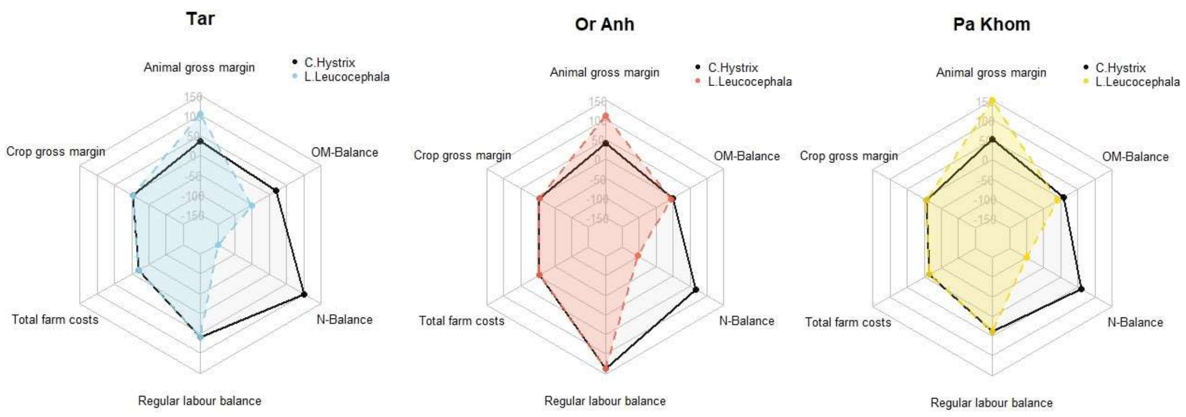

Figure 4

Impact of two possible SPS scenarios on the performance of farms in three villages, in % change with respect to the optimized baseline. Minimum and maximum change was set at -150 and 150% for readability.

3.2.2 Environmental domain

The integration of *C. hystrix* resulted in an increase in the soil organic matter (OM-)balance in Tar (+ 20.5%) and Pa Khom (+ 8.1%), and a slight decrease in Or Anh (- 0.7%) (Table 6). The *L. leucocephala* scenarios all experienced a decline in the OM-balance. It is noteworthy to mention that in Tar, the integration resulted in a decrease of 52.2% in the soil OM-balance, while the impact was relatively lower in the other villages (ranging from -6 to -10%). However, it is important to highlight that these changes are not concerning, as the OM-balance remains positive in all scenarios.

The presence of *L. leucocephala* had a positive influence on the nitrogen (N-)balance due to its N-fixing capabilities, effectively preventing soil depletion in all scenarios. In Pa Khom, the N-balance improved from a negative balance of -20 kg N ha^{-1} y^{-1} to a positive balance of 0.08 kg N ha^{-1} y^{-1}. Conversely, the integration of *C. hystrix*, had a negative effect on the N-balance as more nitrogen is extracted, resulting in a further decline of soil fertility in the long run with for example in Or Anh a negative value of -32 kg N ha^{-1} y^{-1}.

The SPS scenarios influenced the dry matter (DM) and structure feeding requirements due to the increased growth production (kg/day) of the cattle, caused by the thermal comfort provided by the trees. But the influence did not exceed the targeted range (Table C2). The inclusion of *L. leucocephala* in the pasture resulted in an elevated crude protein content of the *B. ruziziensis* (Table C2). This caused the supplied crude protein to surpass the intended targets. In contrast, the integration of *C. hystrix* in the pasture had a negative effect on meeting the crude protein requirements. This is because the reduction in *B. ruziziensis* pasture productivity due to the shading effect from the trees in a SPS design is not counterbalanced by an increase in the crude protein content or the availability of supplementary fodder from the tree, as was observed in the case of *L. leucocephala.* It is worth emphasizing that in the baseline scenario, the total digestible nutrients (TDN) surpassed the intended values in both the Tar and Pa Khom scenarios. The TDN deviated even further from the targeted values in the SPS scenarios, with *C. hystrix* exerting a slightly stronger influence compared to *L. leucocephala.* Only in the scenario of Or Anh did the baseline fall within the desired ranges, but the integration of trees resulted in an exceeding of the targeted TDN values in this case as well.

A notable example of potential supplementary cattle diet options with *L. leucocephala* can be found in a cattle feeding trial conducting by Gill et al. (2020) in Cambodia. In this study, the daily diet of rice straw and grass for cattle was supplemented with *L. leucocephala* sourced from a living fence that surrounded a paddy field. This example could serve as a reference for exploring similar possibilities in the villages of Xieng Khouang. According to their estimates, 1-hectare of approximately 400 meters of living fences with 1,333 trees spaced 30 cm apart, could yield around 133 kg of fresh weight biomass per month. This is equivalent to approximately 66.5 kg of dry weight per month, assuming a 50% dry matter content based on the weighted *L. leucocephala* fodder data of the experiment. Considering a consumption rate of 1 kg of fresh *L. leucocephala* per cow per day (29% of total DM intake), it was projected that a living fence around 1 hectare of land could sufficiently supplement the diets of rice straw and grass for two cows during the dry season (November to May). Expanding this reasoning to the pasture plots of the case study farmers, Tar would be able to supplement the diet of 5 cows, in Or Anh support 2 cows and Pa Khom 8 cows (Table C3). These numbers suggest the potential of utilizing *L. leucocephala* as a supplementary feed source for cattle in these areas.

Table 6

Farm performance results of the modelled FarmDESIGN scenarios of the baseline and the SPS designs in the three villages.

		Economic				*Environmental*	
		Gross margin Animals*	Gross margin Crops*	Total farm costs*	Regular labour balance	N-balance	OM-balance
Village	*Scenario*	*USD y^{-1}*	*USD y^{-1}*	*USD y^{-1}*	*Hours y^{-1}*	*kg N ha^{-1} y^{-1}*	*kg ha^{-1} y^{-1}*
Tar	*Baseline*	3,673	26,892	7,291	1,924	-9	103
	C. hystrix	4,958	25,736	5,877	3,044	-18	125
	L. leucocephala	7,474	25,736	5,877	3,044	6	49
Or Anh	*Baseline*	1,751	14,391	17,120	476	-4	370
	C. hystrix	2,443	13,752	16,374	1,128	-7	367
	L. leucocephala	3,700	13,752	16,374	1,128	0.15	347
Pa Khom	*Baseline*	2,441	17,046	10,382	4,295	-20	577
	C. hystrix	3,727	15,962	8,895	5,952	-32	623
	L. leucocephala	6,241	15,962	8,895	5,952	0.08	525

**1 LAK = 0.000057 USD (May 2023)*

3.3 Focus Group Discussions

3.3.1 Ambitions regarding livestock

All farmers aspired to increase their cattle herd (Table F1), as they expected it could provide a reliable year-round income. This security was particularly appealing to tea-producing farmers, as their income from tea was limited to the period between March and October. Given the slow natural reproduction rate of the cattle, farmers desired a free budget to purchase mature cows to expand their herds. But they were limited by a restricted budget, which prevented them from expanding their cattle herd. A farmer elaborated that purchasing cattle would require tapping into funds allocated for purchasing rice and vegetables.

3.3.2 Perception of soil erosion as a problem

According to the farmers in Or Anh, soil erosion did not occur naturally but only as a result of human activities. In Tar, the weighted average on a 1-10 Likert Scale (with 10 being the farms current biggest problem) was 2.5 (Table F1), as farmers primarily observed soil erosion after seeding *B. ruziziensis* on their plots, which does not happen annually. In Pa Khom, the score was 3.5, as farmers noticed the topsoil of their pasture sliding down in the rainy seasons. They addressed this issue by transplanting pre-grown chunks of pasture into the eroded areas as a solution. When asked about preserving or planting trees to prevent soil erosion, none of the farmers in Pa Khom were aware of this relationship. However, in Or Anh, farmers intentionally preserved large trees to mitigate landslides.

Table 7

Results of the FGDs with the averaged ranking of the tree species and expected problems in the management of a SPS. In each FGD respondents ranked benefits and problems as a group, these three separate rankings have been averaged into one final ranking. Related questions can be found in Appendix D.

Ranking position	*Benefit C. hystrix (Q10)*	*Averaged rank*	*Benefit L. leucocephala (Q14)*	*Averaged Rank*	*Problems SPS (Q17)*	*Averaged Rank*
1.	*Helps against soil erosion*	(3.00)	*Fodder for livestock*	(2.00)	*Buying fences to protect the small trees from cattle*	(2.67)
2.	*Shade for cattle* *Fire Wood*	(3.33) (3.33)	*Soil fertiliser (legume)*	(3.00)	*No money for buying the trees**	(3.67)
3.	*Wood for building*	(3.67)	*Human consumption (leaves, flowers, beans)*	(3.33)	*Not enough labour to plant and manage the trees**	(4.00)
4.	*Harvesting of 'Hed kor Daeng' mushrooms to eat*	(4.00)	*Cultural: medicine, religious believe*	(3.67)	*No knowledge how to manage and plant the trees ; Tree damage by cattle when trees are still small*	(4.67)
5.	*Harvesting of 'Hed kor Daeng' mushrooms to sell*	(4.33)	*Shade for cattle*	(4.67)	*No access to a plant nursery**	(6.67)
6.	*Fruits for human consumption **	(7.00)	*Helps against soil erosion **	(6.33)	-	
7.	-		*Fire Wood **	(7.00)	-	
OUT	*Fruits for cattle to eat*		*Wood for building*		*No market access for selling tree product(s)*	

** In ≥ 1 villages topic labelled as 'not applicable' by respondents, in these cases the lowest possible ranking has been assigned to calculate the total averaged ranking.*

3.1.1 Perspectives on Castanopsis Hystrix

C. hystrix is a widely recognized tree species among farmers and is actively preserved by some of the farmers. All farmers unanimously voted against using the fruits as cattle feed, as they claim that the cattle do not consume them. The most valued benefit of this tree species, as indicated in Table 7, is its ability to prevent soil erosion. This shows an interesting contradiction to their previous perception that soil erosion is not a big concern for them.

The harvesting of *Hed Kor Daeng* mushrooms is another benefit of *C. hystrix* that has been discussed during the FGDs. *C. hystrix* forms a symbiotic relationship with *Hed Kor Daeng* mushrooms. According to research by Foppes & Xayalath (2022), there is a lucrative market for these mushrooms in China. However, due to stricter enforcement of natural preservation laws, the collection of *Hed Kor Daeng* mushrooms from the forest is currently endangered. Cultivating these mushrooms in SPS could provide a sustainable opportunity to increase farmers' cash income. However, it is uncertain whether the symbiosis occurs in a SPS context, as indicated by personal communication with NAFRI[6] and a local expert[7]. The FGDs showed that farmers gave a low value to the benefit of harvesting the mushrooms for consumption or sale (Table 7). More importantly, none of the farmers have personally observed the symbiotic relationship on their own farm plots. Instead, they prefer to continue gathering the mushrooms from the forest. This suggests that this particular benefit of *C. hystrix* may not be applicable to a SPS.

3.1.2 Perspectives on Leucaena Leucocephala

L. leucocephala is also a recognized species, although only two out of 13 respondents have this tree on their farm. Due to its small size, farmers perceive the tree as less useful for construction, firewood, shading and soil erosion control. However, the provision of fodder for livestock is highly valued (Table 7). The farmers were unaware of the N-fixing characteristic of this tree species, but it was explained to them prior to the collective ranking during the FGDs. Interestingly, one farmer personally observed this relationship, as she noticed *B. ruziziensis* did not die when planted near *L. leucocephala*, while it did when planted near other tree species.

3.1.3 Willingness and opinions of a SPS

In the hypothetical situation of creating a SPS, farmers expressed a preference for a scattered design (62%) due to its potential to provide the cattle with shade while grazing (Table F2). They also recognized the soil benefits of N-fixation, leading them to believe that spreading the trees across the plot would be most advantageous for the pasture. The living fence design was the second choice for most farmers (31%). They feared that in this system, the cattle would primarily graze in the shade, potentially leading to the deterioration of the *B. ruziziensis* grass underneath the living fence. However, the farmers did acknowledge the benefits of using trees as fences, though they considered it a challenging system to implement. Farmers indicated a lack of knowledge in tree management, e.g. planting distance, as most of them only had experience with natural tree preservation. Other challenges regarding the management of a living fence system were the lack of labour and a limited budget.

The farmers from Tar, on the other hand, were not enthusiastic about any SPS due to their common practice of annually burning the pasture for improved fertility. Considering the inability to control the fire, preserving young trees or planting trees to set up a SPS would not be possible in this village unless the yearly slash-and-burn practices stop.

Overall, farmers found it difficult to imagine the consequences of a SPS on the farm performance. Opinions strongly differed between the villages. For instance, all farmers from Pa Khom expressed interest in setting up a living fence system on their farm, while all other farmers voted against (Table F1).

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[6] Personal communication, Head of Forest Economics and Technology at the National Agriculture and Forestry Research Institute (NAFRI), 02/03/2023, Vientiane
[7] Personal communication, Rural Development and Conservation consultant, 21/03/2023, Vientiane

4. Discussion

This study aimed to assess the potential contribution of SPS as a pathway for SI and livelihood improvement for crop-livestock smallholder farmers in the Lao uplands.

4.1 Livelihood trajectories

The first objective of this study was the examine the trajectories of farmers' livelihoods over time. Compared to the year 2015, there has been a notable increase in farmers' participation in the market economy. This can be seen as a trajectory of 'depeasantisation', where traditional farming practices are gradually abandoned in favour of intensified agricultural production and integration into the market, aiming to revitalize the agricultural sector (Bouahom et al., 2004; McMichael, 2012). In this context, all types of farms have experienced an increase in total income, with farmers expressing a particular interest in expanding their cattle production and tea business. The cultivation of tea has proven to be a promising pathway for poverty alleviation and rural development among smallholder farmers, as previously predicted by Phouyyavong et al. (2018). This shift towards engaging in diverse activities reflects an increasing reliance on cash-earning activities. A similar trend towards commercial farming was also observed by Phouyyavong et al. (2019) during the period from 2003 to 2016, where Hmong households diversified their livelihoods to supplement swidden farming.

But this reliance shows its drawbacks. While the diversification with tea businesses in Tar and Or Anh has motivated farmers to protect the forest in response to the Chinese market's demand for organically cultivated tea from natural forests, the commercialisation of maize cultivation in Pa Khom has already revealed its unsustainable environmental consequences. Farmers reported a decline in maize production and encountered soil fertility problems, all while being aware of their lack of knowledge to address these issues and the absence of support from Vietnamese purchasing companies. The N-balance of all the modelled farms initially showed negative values, mirroring the soil mining observations reported by Epper et al. (2020) on the same farms in 2017. The fact that the N-balance was lower in Pa Khom, where monoculture maize production is practiced, compared to the scenarios involving tea cultivation, aligns with the findings of Paul et al. (2022).

Across Southeast Asia, the expansion of export-oriented commodity production by agribusinesses has transformed diverse farm-forest landscapes into monocultures focused on commodity crops for downstream industries in Vietnam, China, and Thailand (Cole, 2022). Initially concentrated along the Lao-Vietnam borders, the maize boom has now reached the Xieng Khouang province, as indicated by this study and the research conducted by Paul et al. (2022). The neighbouring province of Houaphan serves as an example of the severe consequences of the maize boom. While farmers experienced a temporary increase in income from maize production, they soon encountered declining yields, soil degradation, and erosion, leading them into a downward spiral. Land previously dedicated to food production has now been repurposed for maize cultivation for animal feed, rendering farmers highly dependent on income for their food security (Cole, 2022). Considering that farmers in Xieng Khouang are already witnessing a decline in production and expressing concerns about their future reliance on maize prices, the experiences in Houaphan can serve as a predictor of potential consequences. However, at present, the surveyed farmers in Xieng Khouang still receive an adequate income, and soil erosion has not yet emerged as a major problem during the FGDs.

Setting up a SI system, which aims to enhance productivity on existing land while mitigating the negative environmental or social consequences (Musumba et al., 2017), is therefore now crucial. Farmers in all three villages hypothesized that in the event of a drop in maize or tea prices, they would shift their focus towards livestock, as they perceive the demand for cattle is more stable. Whilst the movement towards extensive livestock grazing has been subject to criticism (Branthomme et al., 2023; FAO, 2017), is the trend already been set in motion through the involvement of Chinese agribusinesses (Napasirth & Napasirth, 2018). However, as described by Cole (2022), reversing the prevailing status quo of agribusinesses to not avoid the social and environmental responsibility for their investments, pose significant challenges. This is part of a governance discussion surrounding the accountability for the consequences of a transboundary agricultural investment (Cole, 2022; Lu & Schönweger, 2017).

4.2 **Silvopastoral systems**

The primary objective of this study was to identify and evaluate possible silvopastoral designs. Additonally, it aimed to quantify the inputs, outputs and resource flows of two SPS designs, while evaluating their socio-economic and environmental impacts using farm modelling techniques.

The effectiveness of SPS depends on the traits of the selected tree species, the SPS design (e.g. living fence or scattered) and the farm characteristics. From an environmental perspective, a SPS scenario incorporating *L. leucocephala* could be recommended due to its N-fixing ability and provision of fodder. This is particularly beneficial for meeting the feed requirements of the cattle, which showed deficits in the baseline model, especially during the dry season when cattle production relies heavily on free-range grazing on fallow land. Additionally, modelling results indicated that *L. leucocephala* can help prevent negative N-balances. Legume trees like *L. leucocephala* are a key component for the SI of livestock systems in warm-climate regions that face climate change and food security challenges (Dubeux Junior et al., 2017). However, this does not mean that *C. hystrix* is unsuitable, as it offers advantages such as soil erosion control, wood supply and the potential to improve the soil OM-balance. According to a technical report of Yagasaki (2022) are the Fagaceae trees, to which *C. hystrix* belongs, the most suitable species for the design of measures against soil erosion in pasturelands as they are dominant in the natural forests in the Xieng Khouang province. Moreover, *C. hystrix* is more widely accessible to farmers compared with *L. leucocephala.* Nevertheless, relying solely on *C. hystrix* for tree integration may lead to a long-term decline in soil fertility. In the most optimal scenario, would *L. leucocephala* be planted as a living fence tree, replacing dry wood fences, as it grows fast and serves as a fodder hedge. In this design, *C. hystrix* would be integrated as scattered trees in the pastureland, allowing farmers to benefit from natural tree preservation by the surrounding forest.

Regardless of the tree type, the SPS scenarios showed an increase in the gross margin of animal husbandry and available household budget, along with decreased costs and labour requirements in the long-term. In this study it is assumed that the labour hours of a SPS scenario may be higher in the short-term, as farmers have to establish the system (e.g. planting seedlings, watering and weeding), although the saved labour hours from replacing dry wood fences in a living fence design may compensate for it. Short-term costs are expected to be high due to the initial investment in establishing the SPS system, but they are anticipated to decrease in the long term over a period of up to 20 years. However, in a scattered SPS design preferred by most farmers, the reality might be different, as preserved trees can save implementation costs and labour, while still requiring traditional dry wood fences. Although these consequences are not modelled in this study, the results highlight the potential benefits of SPS.

The shade provided by trees offers thermal comfort for cattle, leading to an increase in animal growth production from 0.54 kg/day in the baseline model (Lienhard et al., 2008) to 0.68 kg/day in the SPS designs (Table C1), an average retrieved from scientific SPS animal production experiments (Abdulrazak et al., 1996; Galgal et al., 2000; Jones, 1994; Lemcke & Shotton, 2018; Shelton et al., 2021). Conversely, the shade can negatively affect the pasture productivity (Faria et al., 2018; Paciullo et al., 2010). Studies comparing open pasture with silvopasture have shown a 25% reduction in *B. ruziziensis* yield (Chansiri & Sampet, 2005; Tudsri et al., 2002). Consequently, FarmDESIGN results showed that the crop gross margin would decrease in the SPS scenarios. The shade may also impact soil compaction in shaded areas due to the increase of cattle that look for the thermal comfort in the same area (Paciullo et al., 2010), a major concern for farmers when discussing a living fence design. Nevertheless, Montaya et al. (2021) demonstrated that under low grazing pressure and appropriate tree density, an intercropped system with *Brachiaria* can be viable for feeding cattle.

4.3 Implications

This study has demonstrated the potential contribution of the SI pathway of SPS on the livelihoods of farmers in the Lao uplands. The quantification of the impact of SPS on livelihoods in an Asia-Pacific research context contributes to closing the scientific research gap on this topic (Choocharoen et al., 2014; Shin et al., 2020). The findings of this study can serve as a starting point of the SI-MFS Initiative of CGIAR in Laos to support the integration of trees on pastureland, while protecting ecosystem services. The utilization of FarmDESIGN as a modelling tool has proven to be valuable in analysing the impacts of SPS and has the potential for further expansion.

Furthermore, this study aimed to examine the perspectives and willingness of famers to adopt SPS. A common assumption in agricultural research is that the introduction of innovative technologies will result in technology adoption, and consequently in benefits for the farmers (Cafer & Rikoon, 2018). However, literature demonstrates that this adoption is not self-evident, neither in Laos (Alexander et al., 2020; Sottile et al., 2022). Conversations with local experts[8] have repeatedly revealed that farmers do not express a desire for another short-term training project, as they have experienced numerous of such projects. Through the FGDs conducted during this study, it became evident that not all farmers were enthusiastic about adopting SPS practices. A project in Cambodia that aimed to enhance smallholder livestock systems through the implementation of living fences around rice paddies did not find substantial evidence of farmers widely adopting this practice (Gill et al., 2020). Nevertheless, another project focusing on rainfed lowland rice systems in the Xieng Khouang province indicated that although productivity did not increase, farmers still embraced the innovation due to savings on labour requirement (Bourjac et al., 2017). Farmers aspire for long-term transformations that bridge the gap between empirical evidence, the need of farmers themselves, and the decisions made by policymakers. By using a holistic system approach in this study, the findings underscore the importance of employing mixed methods and indicators derived from various disciplinary dimensions within the agricultural research value chain. The approach enhanced the understanding of the externalities and consequences linked to the adoption of SPS. This scientific implication aligns with the research conducted by Alexander et al. (2020) suggesting that scientists, farmers and policy makers can gain advantage by shifting their emphasis from the introduced technology to the potential users and their behavioural tendencies.

4.4 Limitations of the research

The reliability of the data may have been partly compromised due to errors in survey translation and unknown data, which were rectified by making general assumptions based on existing literature. A specific issue that needs to be addressed is an error found in the survey data concerning labour input for different farm elements. In the survey, farmers often reported working eight hours per day for multiple farm components. Furthermore, it was unclear whether labour tasks were performed by a single household member or involved multiple. To address this, a decision has been made to assume

[8] Employees of Alliance of Biodiversity International & CIAT; Rural Development and Conservation consultant, 2023

the same amount of casual and regular labour for all farms based on the number of working hours and days per year for one working household member. However, it is important to note that in reality, certain tasks may involve multiple individuals instead of just one. As a result, the findings on working hours may not be fully representative, although the overall trends can still be observed.

No available data was found regarding the impact of *C. hystrix* or any related *Fagaceae* species on *Brachiaria* yield. As a result, the use of the same pasture yield as in the *L. leucocephala* scenario is therefore a limitation of the modelling results. Furthermore, there is a lack of data concerning the cultivation costs of a SPS design specific to the Asian-Pacific region. In the absence of such data, the costs associated with a living fence design, as provided by the NAFRI, are utilized for all SPS scenarios. However, it should be noted that the suitability of *C. hystrix* for a living fence might be limited, and that alternative SPS designs (e.g. scattered) could have different implications for the total farm costs. These considerations should be taken into account when interpreting the results obtained from FarmDESIGN.

The calculation of the current level of market orientation was not feasible due to the absence of nutritional data in the survey (Equation 2). Consequently, it was not possible to categorize the farms into the farm types A/B/C/D as done with the data of 2015. This restricted the modelling of SPS scenarios for different farm types.

The approach utilised in this study has limitations, as the 18 farms were averaged into three FarmDESIGN models. Despite efforts to create distinct designs that represent the farms in each specific village, it is still a simplification of reality. The baseline values of the farm performance indicators, serving as the starting point of the SPS exploration, were not always within the desired ranges. However, they did exhibit improvement when compared with the often unrealistic farm performance of the initial scenarios. The findings in this study should be regarded as preliminary observations and should not be generalized further. It is vital to recognize the unique variations among the farms included in this case study.

4.5 **Future research**

This research examined the impact of one leguminous and one non-leguminous tree species within SPS. Future research should expand its scope to encompass a wider range of tree species when modelling the impacts of integrating these trees within a SPS design. This could facilitate the creation of SPS design templates, which can assist policymakers (e.g. NAFRI, DAFO) in providing farmers with knowledge regarding tree species that offer benefits when preserved or planted on their pastureland. Additionally, it is important to note that it was beyond the scope of this study to include a gender-perspective analysis or to differentiate between ethnic groups within the province. Given the ongoing development in the livestock sector, which tends to be more male-oriented (Moglia et al., 2020), future research should incorporate a gender and ethnicity study to gain a comprehensive understanding.

5. Conclusion

The rapid transformations taking place in Laos present numerous opportunities for the country's development. SPS is a strategy that enables smallholder mixed farming systems in the Lao uplands to benefit from these changes in a sustainable and intensified manner. As the commercialization of agriculture leads to environmental trade-offs, SPS offers a viable alternative.

This study focused on examining the potential contribution of SPS to livelihoods of mixed-smallholder farmers in the Xieng Khouang province. Analysis of livelihood trajectories from 2015 to 2023 revealed that livelihoods became more diversified and market-oriented during this period. While commercial agriculture in Xieng Khouang has been an essential livelihood strategy, it results in adverse environmental consequences. Given the government's promotion of the livestock sector and increasing farmer interest in livestock, coupled with negative N-balances and uncertainties in crop productivity, it is crucial to urgently develop a sustainable path forward.

Modelling SPS scenarios using FarmDESIGN demonstrated socio-economic benefits, including increased gross margins of animal husbandry, higher available household budgets, decreased costs, and reduced labour requirements over the long term. The environmental benefits depend on the type of tree integrated in the system. *L. leucocephala* positively influenced the N-balance due to its N-fixing ability and improved feed supply by providing fodder. On the other hand, *C. hystrix* had a negative impact on the N-balance but positively contributed to the soil OM-balance and could be naturally preserved in the surveyed areas. The ideal scenario appeared to involve a scattered design with naturally preserved *C. hystrix* and a living fence with planted *L. leucocephala*.

Constraints for the implementation are a limited budget, labour shortage and a lack of knowledge. While this research serves as a starting point for the further development of SPS in Xieng Khouang through the SI-MFS initiative, it is crucial to pay attention to gender and ethnicity differences and actively involve farmers and policymakers to achieve long-term transformative change.

Acknowledgements
I would like to express my gratitude to CGIAR/CIAT and Wageningen University & Research for giving me the opportunity to conduct my master's thesis within the SI-MFS project. I am thankful to the staff at the CIAT office in Vientiane for their support and assistance throughout my stay. Additionally, I would like to extend my appreciation to the staff at NAFRI, DAFO and PAFO for their translation services and guidance during the fieldwork in Xieng Khouang.

Funding: This work was supported by Wageningen University & Research, in collaboration with the CGIAR Centres/Alliances within the Initiative of Mixed Farming Systems.

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Appendices

Appendix A.

Survey questions

MSc thesis title: The role of silvopastoral systems in swidden transitions: a case study of sustainable intensification in the Xieng Khouang province, Laos PDR.

The information collected is for research purposes and strictly confidential.

1. Do you agree to provide information for this survey?

2. What is your name?

3. What is your position in the household?

4. Are you responsible for the farm related decision making?

   NO -> Who is?

   What is the household role of that person?

5. What ethnic group are you from?

HOUSEHOLD

The following questions are about your household. With household we mean everybody that lives in the house and shares a meal together. This does not have to be all family it can also be permanently employed workers. Family members that live somewhere else, does not count. We would like to know some basic information of each household member to get a good idea of the composition of the farm.

6. How many people are living and sharing meals together in this farm?

   Could you describe of each household member:

7. What is their position in the household?

8. What is their age? *[years]*

9. What is their gender? *[M/F/X]*

10. How many years of education did he/she had? *[years]*

11. In the wet season, does this household member works on the farm or off the farm?

12. In the dry season, does this household member works on the farm or off the farm?

YES to off-farm work -> What kind of off-farm work?

LAND

The following questions are about the land you use for farming.

13. What Local Land Unit do you use?

14. Is there a difference in the amount of land that you have in the wet season versus dry season?

YES -> [Ask questions below twice, once for wet season, once for dry season]

15. How much land do you cultivate?

16. Do you lease land?

YES -> How much land? *[Hectares]*
How much do you charge?

17. Do you lease-out land?

YES -> How much land? *[Hectares]*
How much does it cost?

18. In how many plots is your land divided?

GENERAL PLOT INFORMATION

The following questions are about how you use your land. We would like to understand what crop cultivation you use on which part of your farm. Therefore we are going to draw the farm together, with all the plots and smaller divisions of the plots and write down all the crops you cultivate in each plot. A plot means the same location and same crop pattern for that year. For both the wet season and the dry season, written down in different pen colours. Crops include forages and home garden.

[INSTRUCTIONS:

1. Make a drawing of the farm to clarify the plots per season and number them (Plot #1, #1.1, #2, #2.1 etc.)
2. Details all the crop in all plots per season
3. Include ponds, fallow, tree-plots, home garden and grazing areas managed by the household.]

19. Do you have a home garden?

[For each plot and/or subplot, ask the following questions]

20. What is the size of the plot? *[Hectares]*

21. Do you own the plot or do you rent it?

22. Which crops do you grow on this plot in the WET season?

23. Are the crops intercropped in the WET season?

24. Which crops do you grow on this plot in the DRY season?

25. Are the crops intercropped in the DRY season?

NO to intercropping questions -> Go to 'Crop input use and farming activities consuming labour and inputs'.

YES to intercropping questions ->

INTERCROPPING

[Make sure it is clear about which plot the following questions are asked, and about which season (dry/wet)]

26. How much of the plot do you use for each crop?
(% or hectares of the field for Crop A, % or hectares of the field for Crop B etc.)

CROP INPUT USE AND FARMING ACTIVITIES CONSUMING LABOUR AND INPUTS

The following questions are about how much labour and inputs there are required for each of the crops that you cultivate on the farm. When talking about labour, we divide this into 3 different categories.

[Ask the following questions for EACH crop]

27. How many days and how many hours per day do family members or permanent hired employees work for Crop X? (regular labour) This does not include employees that are there temporarily *[# days + hrs/day].*

28. Do you have temporarily hired employees, for example in the peaks of harvesting?

YES -> How many days and how many hours per day do you have temporary hired personnel for Crop X? *[# days + hrs/day]*

29. What are the costs for cultivating Crop X? *[LAK/hectare]*

CROP PRODUCTION

The following questions are about the crop products that you have from the different crops that you grow. We will discuss each crop separately. This includes the residues that you have from the crop.

30. What crop products do you have from Crop X?

We will now ask questions per crop product.

31. What is the fresh yield of this crop product? *[kg / unit]*

32. How much do you sell for the market? *[kg DM/ % /unit]*

33. What is the price you get for the product? *[LAK /kg/ unit]*

34. What do you do with the residues?

35. Is the product or the residues also used for:

36. Green manure?
YES -> How much? *[kg DM / % / unit]*

37. Feed for animals?
YES -> How much? *[kg DM / % / unit]*

38. Bedding for animals?
YES -> How much? *[kg DM / % / unit]*

39. For Home consumption?
YES -> How much? *[kg DM / % / unit]*

40. For burning?
YES -> How much? *[kg DM / % / unit]*

41. For Fire wood?
YES -> How much? *[kg DM / % / unit]*

42. For energy production?
YES -> How much? *[kg DM / % / unit]*

FERTILIZER

The following questions are about the fertilizers that you use for your crops on the different plots. This includes animal manure.

43. Do you use fertilizer?

YES -> On which plots do you use fertilizer?

[Instruction: Write down the plots with the fertilizer on the farm drawing. Ask for each plot separately]

44. On which crops in this plot do you use the fertilizer?

45. What type of fertilizer do you use on this plot?

46. How much of this fertilizer do you use on this plot? *[kg/ha]*

47. What is the price of this fertilizer? *[LAK/kg]*

SCATTERED TREES

The following questions are about the presence of trees on your farm land.

48. Do you have trees on your farm?

49. What kind of tree species?

50. Do you grow any of your crops mixed with trees?

51. How many trees do you have of this species? *[#]*

52. On what plots are the trees located? *[# plot number]*

53. Do you harvest the trees?

YES -> What is the Fresh Yield? *[kg / unit]*

54. How much do you sell for the market? *[kg DM/ % /unit]*

55. What is the price you get for the Tree product? *[LAK /kg/ unit]*

56. Is the product also used for:

57. Green manure?
YES -> How much? *[kg DM / % / unit]*

58. Feed for animals?
YES -> How much? *[kg DM / % / unit]*

59. Bedding for animals?
YES -> How much? *[kg DM / % / unit]*

60. For Home consumption?
YES -> How much? *[kg DM / % / unit]*

61. For burning?
YES -> How much? *[kg DM / % / unit]*

62. For Fire wood?
YES -> How much? *[kg DM / % / unit]*

63. For energy production?
YES -> How much? *[kg DM / % / unit]*

LIVESTOCK

The following questions are about the livestock on the farm. We would like to get as many details about the livestock animals on your farm as possible.

64. Do you have livestock on your farm?

NO -> Go to expenditure farm level.

YES ->

65. What kind of livestock species do you have?

66. Do you try to keep your animals separate from your crops and trees, or do you mix them on the same piece of land?

The following questions are focused on 1 livestock species at a time:

67. What breeds?

68. How many of this livestock breed do you have at the moment? *[#]*

69. How many young animals? *[#] Age: Adult (>6mo for small ruminants & >3yr/1st calving for large)*

70. How many adult animals? *[#]*

71. Do you milk this livestock species?

YES -> How many animals do you milk? *[#]*

72. Do you use this livestock species as a draught animal?
YES -> How many do you use as draught animals? *[#]*

73. How many of this livestock species do you sell per year? *[#/year]*

74. How many of this livestock species do you buy per year? *[#/year]*

75. What type of feed does this livestock species get?

[Ask per feed type]

76. How much of this feed type does the animal get per day? *[Kg/day]*

LIVESTOCK PRODUCTS

The following questions are about the different products you have from the livestock. We discuss each livestock product separately.

77. What products do you have from Livestock species X?

[Ask per livestock product]

78. What is quantity produced? *[kg / litre / unit]*

79. How much do you sell for the market? *[kg DM/ % /unit]*

80. What is the price you get for the product? *[LAK /kg/ unit]*

81. Do you use the livestock product for Home consumption?

YES -> How much? *[kg DM / % / unit]*

82. Do you also use the livestock product for other purposes, except for the market or home consumption?

YES -> How much? *[kg DM / % / unit]*

LIVESTOCK LOCATIONS

The following questions are about where the livestock is located throughout the year. We discuss the dry and wet season separately.

[Ask for each livestock species]

DRY SEASON:

83. Where do you keep the animals?

84. How many hours per day are they in a stable or barn? *[hrs/day]*

85. How many hours per day are they in the field of pasture? *[hrs/day]*

86. How many hours per day are they in the yard? *Farm yard = on farm area, surrounding buildings. [hrs/day]*

87. How many hours per day are they off the farm? *[hrs/day]*

LIVESTOCK INPUT USE AND FARMING ACTIVITIES CONSUMING LABOUR AND INPUTS

The following questions are about how much labour and inputs there are required for each of type of livestock on the farm. When talking about labour, we divide this into 3 different categories.

[Ask the following questions for EACH livestock type]

88. How many days and how many hours per day do family members or permanent hired employees work for Livestock X? (regular labour) This does not include employees that are there temporarily. *[# days + hrs/day]*

89. Do you have temporarily hired employees?

    YES -> How many days and how many hours per day do you have temporary hired personnel for Livestock X? *[# days + hrs/day]*

90. What are the costs per animal for livestock species X? This is only about costs on the individual animal level, so for example, vaccinations. *[LAK/animal]*

MANURE

The following questions are about the manure of the livestock on your farm.

[Discuss for EACH livestock type]

91. Do you collect the manure from livestock species X?

YES ->

92. How much manure do you collect from livestock species X? *[kg]*

93. For what do you use the manure?

94. Apply to the field?
    YES -> How much? *[unit / %]*

95. Sold?
    YES -> How much? *[unit / %]*
    How much LAK do you get for it? *[LAK/unit]*

96. Used for fuel?
    YES -> How much? *[unit / %]*

97. Any other usages?
    YES -> How much? *[unit / %]*

98. How do you store the manure?

1- Applied fresh without storage *2- Open heap* *3- Under roof* *4- Sealed* *5- Other*

99. How many weeks do you store the manure in that way? *[Weeks]*

EXPENDITURE FARM LEVEL

These questions are all about total costs for the entire farm.

100. Do you hire casual labor?

YES -> How much do you pay per hour? *[LAK/hour]*

101. Do you hire regular labor?

YES -> How much do you pay per hour? *[LAK/hour]*

102. What costs for the animals do you have that are not related to individual animals, such as fencing, or other costs for the entire herd per year? *[LAK/year]*

103. Do you purchase feed for the animals?
YES -> How much LAK/year?
[General costs are sufficient. If farmer does not know, try to discover by asking the categories of costs with these questions or if farmer does know more details]

104. Do you have any other costs?

105. Fertilizer?
YES -> How much LAK/year?

106. Ploughing?
YES -> How much LAK/year?

107. Seeds?
YES -> How much LAK/year?

108. Pesticides/Herbicides?
YES -> How much LAK/year?

109. Machinery?
YES -> How much LAK/year?

INCOME

The following questions are about the incomes per year.

110. What is your yearly total income from the farm? *[LAK/year]*

111. What is your yearly total income from off-farm work? *[LAK/year]*

112. Do you have any other forms of income?
YES -> What type of income?
How much? *[LAK/year]*

SILVOPASTURAL ELEMENTS

113. Would you be willing to plant (more) trees on your farm land? Why yes/no ?

114. What do you think can be the benefits of trees on your farm?

115. What do you think can be the constraints of trees on your farm?

116. What type of trees would you be willing to plant? And with what purpose?

117. Where on your farm land would you plant the trees?

CHANGES

118. What have been the biggest changes in your farm over the last 10 to 5 years?

119. What is your biggest concern?

120. What are your plans for the future?

Before we finish, do you think there is anything important that we have missed?

Do you have any questions or comments?

[Ask for a tour around the farm]

[Thank them for their time and sharing the information.]

Appendix B.

Livelihood trajectory analysis per farm type

Table B1

Livelihood characteristics of the 18 surveyed farms categorized in four different farm types, comparing the situation of 2015 based on a RHoMIS dataset (Ritzema et al., 2019) *and the collected survey data in 2023.*

Farm type	Year	Cumulative diversity	Market Orientation	Household Size	Land owned	Livestock holdings	Total Farm income
		#	*%*	*Persons*	*Hectares*	*TLU*	*USD y^{-1} ** *
A	2015	9.9	5.23	9.60	3.84	8.81	5,193.99
	2023	8.6	-	7.60	10.94	12.05	10,117.52
B	2015	10.8	70.44	7.80	3.68	6.25	1,970.47
	2023	10.2*	-	6.20	13.25	14.19	4,872.00
C	2015	4.0	0.29	4.00	0.55	0.47	2.13
	2023	7.3	-	4.50	4.96	1.78	1,479.00
D	2015	3.3	82.88	5.25	2.43	1.16	592.14
	2023	6.8	-	5.75	3.95	4.31	5,513.33

**Significant change between 2015 and 2023 (p-value ≤ 0.05)*
***The total farm income derived from the RHoMIS 2015 dataset have been converted to the 2023 USD ($) exchange rate.*

Appendix C.

Supplementary FarmDESIGN data

Table C1

Overview of the overall differences in the scenarios in FarmDESIGN.

Scenario	Animal production growth	Pasture cultivation costs	Pasture labour	Herd labour*	Pasture yield*	Pasture crude protein	Pasture N-content
	kg day	*USD ha⁻¹ y⁻¹*	*h ha⁻¹ y⁻¹*	*h y⁻¹*	*kg ha⁻¹*	*g kg DM*	*g 100 g DM*
Baseline	0.54[xiii]	177.79[xiv]	170	-	-	91[xv]	1.46[xv]
C. hystrix	0.68[xvi]	128.76[xiv]	67.5	- 25%[xvii]	-25%[xviii]	91	1.46
L. leucocephala	0.68	128.76	67.5	- 25%	-25%	102.8[xix]	1.65

**Values differ between villages as averages are used from the collected survey data per village. Therefore, only the trend in % is given.*

[xiii] (Lienhard et al., 2008)
[xiv] *Head of Forest Economics and Technology at the National Agriculture and Forestry Research Institute (NAFRI), personal communication, 06/03/2023, Vientiane.*
[xv] *Feedipedia, Congo grass (Brachiaria ruziziensis), 2023.*
[xvi] (Abdulrazak et al., 1996; Galgal et al., 2000; Jones, 1994; Lemcke & Shotton, 2018; Shelton et al., 2021)
[xvii] *According to DAFO (28/03/2023), SPS saves the farmer labour time to look for the cattle, makes it easier to recognise diseases and allows a cut-and-carry system. Own estimates of labour hours based on survey data.*
[xviii] (Chansiri & Sampet, 2005; Tudsri et al., 2002)
[xix] (Chansiri & Sampet, 2005)

Table C2

Results of the feed requirement and the free budget from the modelled FarmDESIGN scenarios of the baseline and the SPS designs in the three villages. Numbers in red indicate values outside of the targeted feed requirements: structure (> 100%), crude protein (100-130%), energy (95 – 105%) and dry matter (≤ 100% of saturation).

		Feed requirements				*Economic*
		Structure availability	Crude protein availability	Energy availability*	Dry matter intake availability	Free budget**
Village	*Scenario*	*%*	*%*	*%*	*%*	*USD y⁻¹*
Tar	*Baseline*	560.95	40.15	-9.84	-10.95	11,611.00
	C. hystrix	406.05	9.48	-28.14	-27.97	11,739.95
	L. leucocephala	620.03	51.79	-17.93	-22.65	14,254.08
Or Anh	*Baseline*	1.15	48.04	2.84	-75.14	578.45
	C. hystrix	-15.21	24.10	-11.66	-78.30	631.40
	L. leucocephala	50.30	119.90	17.19	-74.80	1,888.47
Pa Khom	*Baseline*	410.64	28.65	-14.41	-27.64	10,768.97
	C. hystrix	306.23	7.76	-27.18	-39.11	10,970.01
	L. leucocephala	558.89	58.26	-13.25	-32.12	13,484.13

**Total digestible nutrients (TDN)*
***1 LAK = 0.000057 USD (May 2023)*

Table C3

Tar
*L. leucocephala per 1 hectare (4 * 400 meter): 133 kg*
Pasture: 2.63 hectare
*L. leucocephala per pasture: 133 * 2.63 = 349.79 kg*
*1 hectare (4 * 400 meter) = supplementary L. leucocephala feed diet of 2 cows*
*(349.79 * 2) / 133 = 5.27 ~ 5 cows*

Or Anh
*L. leucocephala per 1 hectare (4 * 400 meter): 133 kg*
Pasture: 1.08 hectare
*L. leucocephala per pasture: 133 * 2.63 = 349.79 kg*
*1 hectare (4 * 400 meter) = supplementary L. leucocephala feed diet of 2 cows*
*(349.79 * 2) / 133 = 2.17 ~ 2 cows*

Pa Khom
*L. leucocephala per 1 hectare (4 * 400 meter): 133 kg*
Pasture: 4.1 hectare
*L. leucocephala per pasture: 133 * 4.1 = 545.3 kg*
*1 hectare (4 * 400 meter) = supplementary L. leucocephala feed diet of 2 cows*
*(545.3 * 2) / 133 = 8.22 ~ 8 cows*

Appendix D.

Focus Group Discussion questions

MSc thesis title: The role of silvopastoral systems in swidden transitions: a case study of sustainable intensification in the Xieng Khouang province, Laos PDR.

<u>The information collected is for research purposes and strictly confidential.</u>

Focus Group Discussions

Location: Xieng Khouang, Pek District, Villages: Tar, Or Anh, Pa Khom.

Purpose: All the farmers that are surveyed in February 2023 are invited to join a Focus Group Discussion. The data that has been collected during the survey is analysed. In a modelling program the future scenario of integrating trees as a 'living fence' on the Ruzi plots is configurated. The selected trees are: *Leuceana Leucocephala* and *Castanopsis hystrix*. Integrating trees on a pasture with cattle is part of a 'silvopastoral system', which is the main focus of this research.

The main purpose of the Focus Group Discussion is to discover the willingness of the farmers to adopt silvopastoral elements on their farms, and to find out their opinions about the possible benefits and constraints. The results of the modelled scenario's will be discussed with the farmers. For example, influence on farm income, labour hours and animal productivity.

Topics include risk perception, motivation, willingness to adopt, resources and available knowledge and support.

The discussion will be set up in a way that the participating farmers discuss these scenario's together in an interactive way. The discussion will be moderated together with a translator (Khamla).

<u>START WITH:</u>

Welcome,

Thank you for participating.

The information during this discussion is only for research purposes, and strictly confidential. Your personal answer will not be shared with the government, or any other party. And will be made anonymous, that is why you will all receive a 'number'.

This session will take about 1 to 1.5 hours. You are encouraged to give your opinions and ideas any time. Also, when you think some relevant topics are missing or when you think some things that are mentioned are not true or not mentioned for your situation.

The interview will be recorded. But that is only for me, when I forgot something to write down.

Is everybody okay with participating with this interview and okay with recording? It is okay to say no.

CATTLE

1. How important is keeping livestock for you?

1: not important
5: Neutral
10: The most important element on my farm
Put vote on the poster.

2. Who wants to have more cattle?
   - Why?

Hand up = YES

Ask why, if no answers: Select 2 farmers that raised hand.

3. What stops you from having more cattle now?
   - Why is that a problem?

Open questions

Farmers can discuss and respond to each other's answers. Multiple reasons need to be given (e.g. labour shortage, fencing, need the land for cash crops).

EROSION PROBLEM

4. How big is the erosion problem for you on your plots?

Rank on printed scale:
1: Not a problem
5: Neutral
10: My biggest problem on the farm
Place vote on number

5. Did you think of any solution?
   - Yes, which solutions?

Hand up = YES

Select farmers that raised hand -> ask: Which solutions?

6. Who considered planting trees against soil erosion?
    - Yes, which tree and where did you plant?
    - Yes, why not planted yet?

Hand up = YES

Select farmers that raised hand.

TREES

Castanopsis Hystrix (Mai Kor Daeng)

Show posters with Mai Kor Daeng, let farmers observe

Hand up = YES

7. Who knows this tree?

8. Who has this tree on their land?

Hand up = YES

9. Do you know other farmers that use *Mai Kor Daeng* on their farm?

Hand up = YES

10. What do you think is the most important benefit of *Mai Kor Daeng*?
    1. Helps against **erosion**, protect the soil
    2. **Shade** for cattle
    3. **Fire wood**
    4. Fruits for **human** consumption
    5. Fruits for **feed cattle** to eat
    6. Harvesting of 'Hed kor Daeng' **mushrooms to sell**
    7. Harvesting of 'Hed kor Daeng' **mushrooms to eat**
    8. Wood for building

Benefits are printed on paper.

Farmers together rank the benefits. From most important to not important for them.

Leucaena Leucocephala (Mak Ka Thin)

Show posters with Mak Ka Thin, let farmers observe

11. Who knows this tree?

Hand up = YES

12. Who has this tree on their land?

Hand up = YES

13. Do you know other farmers that use *Mak Ka Thin* on their farm?

Hand up = YES

14. What do you think are the most important benefit of *Mak Ka Thin*?
    1. Helps against **erosion**, protect the soil
    2. **Shade** for cattle
    3. **Fire wood**
    4. **Fodder** for livestock
    5. **Human consumption** (leaves, flowers, beans)
    6. Soil fertiliser (Nitrogen, legume)
    7. **Cultural:** medicine, religious believes.
    8. **Wood for building**

Benefits are printed on paper.

Farmers together rank the benefits. From most important to not important for them.

<u>SILVOPASTURAL DESIGN</u>

15. If you plant trees on your ruzi plot, how would you design this?
    1. Living fence
    2. Rows
    3. Scattered

- Why this design (the most voted for)?
- Why not 1?

Show poster with different designs.

Each farmer vote on their preferred design.

What if we continue with design 1 Living Fence, and we use one of the trees that we discussed before.

16. If you would have design 1, what do you think will be problems for starting and managing? Why?

Open questions.

Make sure everybody answers.

17. Possible problems with this system are showed. Can you together rank the problems, from biggest problem to smallest problem? If you think something is not a problem, you can leave it out.
    1. Not enough **labour** to plant and manage the trees
    2. No **market access** for selling tree product(s)
    3. No access to plant **nursery**
    4. No **knowledge** how to manage and plant the trees
    5. No **money** for buying the trees
    6. Tree **damage** by cattle when tree still small
    7. **Buying fences** to protect the small trees from cattle

Problems are printed on A4.

When new problems have been discussed, write it down on A4 to add in this question.

Farmers rank the problems, from biggest problem to no problem.

18. Do you think it is possible to harvest Hed kor Daeng mushrooms with this system on pastureland with the Mai Kor Daeng tree?
    - Why / why not?

Let farmers discuss.

19. If you would have Design 1, what do you think will happen with:
    - Yield Ruzi: UP or DOWN?
    - Soil fertility: UP or DOWN?
    - Costs: UP or DOWN?
    - Labour: UP or DOWN?

Hand up = UP

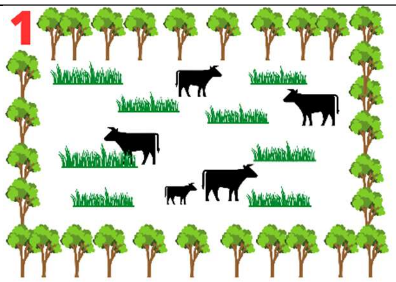
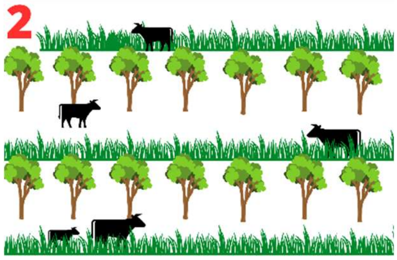
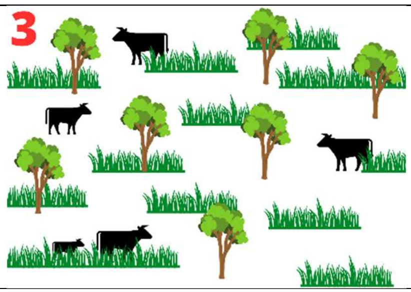
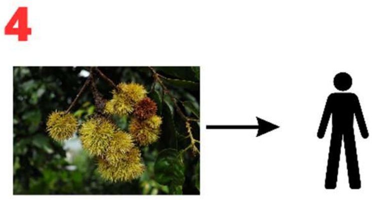
Let farmer discuss each consequence together, why do they think up/down?

20. Now that we talked about possible benefits and problems, would you be interested in setting up a system (with any tree) in the living fence design? Why?

Hand up = YES

Appendix E.

Focus Group Discussion visuals

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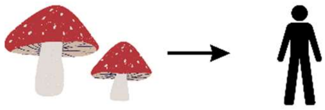
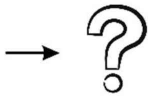
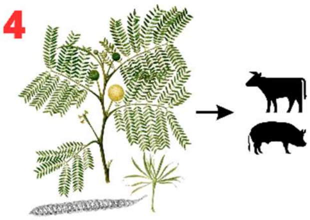
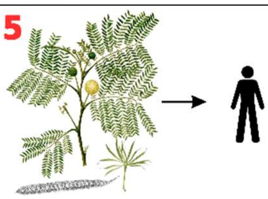
7 	2 
4 	3 
5 	4 
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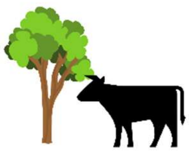
7	6 
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Appendix F.

Focus Group Discussion results

Tar: 2 respondents, all male.
Or Anh: 5 respondents, 2 male.
Pa Khom: 6 respondents, 4 male.

The answers to questions 9 and 14 have not been recorded here, as the answers to these questions proved to be of no value in relation to questions 8 and 13.

Table F1

Results of the closed questions of the focus group discussions, categorized per village expressed in % of the total respondents in each village.

Village	Q1	Q2	Q4	Q7	Q8	Q11	Q12	Q20
		% yes		*% yes*	*%*	*%*	*%*	*% Yes*
Tar	8.33	100	3.5	100	50%	100	0	100
Or Anh	10	100	2.5	100	0%	100	0	0
Pa Khom	9	100	1	100	100%	100	40	0

Table F2

Result of Question 15, farmers preference for a SPS design. Expressed as a percentage of all respondents.

Q15: SPS design	Q15
	%
Living fence	31
Rows	8
Scattered	62

Table F3

Result of Question 19, perspectives on a SPS on different farm performance indicators. Expressed as a percentage of all respondents.

Q19: Consequences SPS	Up	Down
	%	*%*
Yield *B. ruziziensis*	56	44
Soil Fertility Pasture	46	54
Total Farm Costs	62	38
Total Farm Labour	29	71