Activity Report

Productivity impacts and Environmental trade-offs of Livestock-based systems in the Northern uplands of Lao PDR

December 2025

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Contents

Introduction

Livestock production in the upland areas of northern Laos, particularly in Xiengkhouang and Luang Prabang provinces, forms a cornerstone of rural livelihoods and economic development. Cattle and buffalo serve as crucial household assets, providing income, and social capital among ethnic communities such as the Hmong and Khmu. Driven by growing domestic and regional demand for meat, particularly exports to Vietnam and China, the Lao government has prioritized expanding livestock production in these northern regions (Philp et al., 2024; Dao et al., 2025).

Despite this potential, livestock production in the uplands faces persistent structural challenges. Feed shortages remain the most critical constraint to productivity and typically extend over a prolonged period of up to six months (November to April). During this period, farmers rely heavily on Ruzi grass (*Urochloa ruziziensis*), natural pastures, and crop residues such as maize stover and rice straw, whose nutritional quality and availability decline sharply in the dry months. Consequently, animal growth rates and reproductive performance remain low, and household feed insecurity limits the capacity to scale up production (Philp et al., 2024).

The pressure on feed resources has been intensified by land-use competition and environmental degradation. The rapid expansion of maize and reduced fallow periods have displaced grazing areas and decreased soil fertility, while uncontrolled grazing on steep slopes contributes to soil erosion and reduced vegetation cover (Phouyyavong et al., 2019). These pressures have created a delicate trade-off between productivity and environmental sustainability, with many upland systems now facing declining resilience to climate variability.

To better understand these dynamics, a baseline environmental assessment of livestock systems was conducted in Nonghet District, Xiengkhouang Province (Dao et al., 2025), complemented by a feed resource analysis using the Gendered Feed Assessment Tool (G-FEAST) (Philp et al., 2024). Together, these studies identified distinct farm typologies and demonstrated that more than 70% of upland households face seasonal feed deficits during the dry months, with limited adoption of improved forages.

The baseline findings highlighted the need for context-specific interventions that both address feed scarcity and mitigate environmental impacts. In particular, integrating improved forages, managing grazing lands more efficiently, and strengthening crop-livestock linkages were identified as promising pathways for sustainable intensification. However, these interventions must be carefully designed to fit local agroecological and socioeconomic conditions and to minimize trade-offs related to land, water, and emissions.

Building on this foundation, the present report develops intervention scenarios for sustainable livestock intensification in Nonghet District. The scenarios focus on two representative farm types identified in the baseline typology including extensive livestock-oriented systems (Type 1) and semi-intensive mixed systems (Type 4), which together capture the main livestock-based production systems and environmental gradients of the region (Dao et al., 2025).

To design these interventions and assess their environmental implications, the study integrates three complementary decision-support tools (DSTs):

1. G-FEAST[1], to characterize baseline feed resources and seasonal feed gaps;
2. Tropical Forages selection tool[2], to identify suitable drought-tolerant forage options for upland environments based on climate, soil, and management conditions; and

[1] Gendered feed assessment tool (G-FEAST): https://gender.cgiar.org/tools-methods-manuals/gendered-feed-assessment-tool-g-feast

[2] Tropical Forages selection tool: https://tropicalforages.info/text/intro/index.html

3. CLEANED (Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment, and Sustainable Development)[3], to evaluate the productivity and environmental trade-offs of baseline and intervention scenarios.

4. D4R Tool (Diversity for restoration)[4], a tool for planning "what" to plant.

By applying these integrated tools, the study generates evidence-based recommendations for improved feed availability and livestock productivity while maintaining ecosystem integrity. The results are intended to guide future interventions under the ASEAN-CGIAR Innovate for Food and Nutrition Security Regional Program to demonstrate how decision-support tools can inform sustainable livestock development and act as a pathway for scaling regenerative agri-food system innovations. This study is also part of the CGIAR Science Programs on Sustainable Farming (SF) and Sustainable Animal and Aquatic Foods (SAAF), ensuring continuity in generating actionable evidence for sustainable intensification in upland livestock systems in Southeast Asia.

[3] Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment, and Sustainable Development (CLEANED): https://alliancebioversityciat.org/tools-innovations/cleaned

[4] D4R Tool (Diversity for restoration): https://www.diversityforrestoration.org/

Methods

2.1 Study Area

The study was conducted in Nonghet District, located in the eastern part of Xiengkhouang Province, Lao PDR. The district is characterized by a mountainous and dissected terrain, with elevations ranging approximately from 900 to 1,500 m above sea level, resulting in limited flat land, fragmented farm plots, and a strong dependence on sloping upland fields for both crop and livestock production (Dao et al., 2025).

Nonghet lies within a tropical monsoon climate zone, with a pronounced seasonality that strongly shapes agricultural activities. The rainy season typically extends from May to October, while the dry season spans November to April, during which biomass is limited and water availability declines (Philp et al., 2024; Dao et al., 2025). Average annual rainfall is reported to range between 1,200 and 1,800 mm, with substantial interannual variability, increasing the exposure of farming systems to climatic risk, particularly during the late dry season (Philp et al., 2024).

Agriculture is the primary livelihood activity in Nonghet District, reflecting broader land use patterns observed across northern upland Laos. Farming systems are typically diversified and mixed, combining upland rice, paddy rice in valley bottoms, maize, cassava, and small areas of planted forages. Cropping systems are often organized through rotations or intercropping arrangements as a strategy to manage production risks associated with soil erosion, declining fertility, and climate variability (Vongvisouk et al., 2014). Expansion of maize and other commercial crops has increased pressure on land resources in recent decades, contributing to changes in grazing access and feed availability for livestock.

Livestock plays a central role in household livelihoods in Nonghet District. Cattle and buffalo are the dominant large ruminants, complemented by pigs and poultry. Livestock contributes to income generation, savings, and nutrient cycling through manure use. Cattle production systems in the uplands are predominantly extensive or semi-intensive, relying on communal grazing areas, natural pastures, planted forages such as Ruzi grass (Urochloa ruziziensis), and crop residues including maize stover and rice straw (Phouyyavong et al., 2019). Seasonal feed shortages are common, particularly during the prolonged dry and early wet seasons, when forage biomass and quality decline.

The district faces several interlinked environmental constraints that influence agricultural productivity and sustainability. Soil erosion on sloping land is a persistent challenge, especially where continuous cropping or overgrazing occurs. Nutrient depletion and declining soil fertility have been widely reported in upland systems of northern Laos, linked to shortened fallow periods, crop intensification, and limited use of soil amendments (Guillaume et al., 2011). These pressures are compounded by limited access to irrigation and increasing competition for land between crops and livestock.

These biophysical and socio-economic characteristics make Nonghet District a representative case for evaluating feed-based and silvopastoral interventions aimed at improving livestock productivity while reducing environmental degradation. The district therefore provides a suitable context for applying integrated decision-support tools to assess environmental trade-offs and identify sustainable intensification pathways for upland livestock systems in northern Lao PDR.

2.2 Farm Type Selection

The classification of farm types in this study is derived from the 2024 household survey conducted under the CGIAR initiative on Mixed Farming Systems (MFS) in Xiengkhouang

Province, which covered 300 households across 14 villages in Kham, Mok, and Nonghet districts (Zepeda et al., 2025). The survey collected detailed data on household structure, crop and livestock activities, land use, income sources, and resource availability.

Using principal component analysis and hierarchical cluster analysis, five distinct farm types were identified, capturing the diversity of highland maize–mixed farming systems in the study area. These farm types differ in their degree of crop–livestock integration, land and livestock endowments, mechanisation, and income orientation. The distribution of households across the five types is as follows:

Type 1: Extensive mixed farms with greater pasture orientation (15.7%)

Larger farms with relatively large cattle herds, a high share of natural and cultivated pasture, and lower dependence on crop income. These systems rely heavily on grazing and are vulnerable to dry season feed shortages and pasture degradation.

Type 2: Small, irrigated and diversified farms (21.7%)

Small landholdings with access to irrigation, high paddy rice yields, diversified income sources, and relatively low livestock integration.

Type 3: Small, crop-focused farms with limited mechanisation (20.0%)

Farms dominated by crop production, minimal pasture and livestock, low mechanisation, and strong dependence on cropping for income.

Type 4: Semi-intensive mixed farms / maize-dominant farms (23.7%)

Small farms oriented towards maize and upland rice production, with limited pasture, small livestock herds, partial stall feeding, and high dependence on crop residues for feed.

Type 5: Large, diversified mixed farms (19.0%)

Larger, mechanised farms with a balanced combination of crops and livestock, cultivated pasture, and relatively high and diversified farm income.

While these typologies provide an important overview of farming system diversity in Xiengkhouang Province, the study focuses specifically on crop–livestock systems with clear relevance for forage development and land-management interventions. For this reason, type 1 and type 4 farms are retained for in-depth analysis in this report.

Type 1 represents extensive, pasture-oriented systems where livestock plays a central role and where interventions targeting forage improvement, grazing management, and feed availability are most critical. In contrast, Type 4 represents semi-intensive crop–livestock systems characterised by maize dominance, limited pasture, and increasing reliance on crop residues and partial stall feeding. Together, these two types capture the main management and environmental gradients relevant to sustainable intensification in the northern uplands of Laos.

Table 1. Characteristics of Livestock systems in Type 1

Parameter	Typical characteristics (baseline)
Herd composition	30 cows, 6 adult males, 6 steers/heifers, 6 calves, 2 fighting bulls, 4 pigs
Land area (total)	30 ha
Land used for feed production	22.8 ha (mainly natural and Ruzi pastures)

Parameter	Typical characteristics (baseline)
Feeding system	Predominantly grazing, limited supplementation
Major feed sources	Natural pastures, Ruzi grass, Napier grass, maize stover, rice straw
Management intensity	Extensive, low input
Environmental constraints	Overgrazing, erosion, declining soil fertility

Table 2. Characteristics of Livestock systems in Type 4

Parameter	Typical characteristics (baseline)
Herd composition	4 cows, 2 male cattle, 5 heifers, 4 calves, 1 fighting bull, 3 sows/boars and 8 growers
Land area (total)	5 ha
Feeding system	Semi-stall feeding and partial grazing
Major feed sources	Natural pasture, Ruzi grass, maize stover, rice bran, maize grain
Management intensity	Moderate input, integrated
Environmental constraints	Land scarcity, erosion, crop residue competition

2.3 Decision-Support Tools

The identification and evaluation of intervention scenarios were guided by three complementary **Decision-Support Tools (DSTs)**: **G-FEAST**, **Tropical Forages selection tool**, **CLEANED and D4R**. Together, these tools provide an integrated framework to understand feed resource constraints, identify suitable forage options and tree species, and assess environmental trade-offs associated with livestock interventions.

2.3.1 Gendered Feed Assessment Tool (G-FEAST)

The International Livestock Research Institute (ILRI) has developed the Gendered Feed Assessment Tool (G-FEAST) to guide livestock feeding strategy development. G-FEAST was employed to characterize the local feed resource base and quantify seasonal feed gaps in Nonghet District. G-FEAST integrates participatory assessments with quantitative feed data, allowing both male and female farmers to rank feed types by availability, quality, cost, and labor contribution. The tool then converts these rankings into feed basket proportions for rainy and dry seasons, linking them with nutritional attributes (dry matter, crude protein, and metabolizable energy).

In this study, G-FEAST data provided the baseline feed composition data for Type 1 and Type 4 farms, highlighting the predominance of natural pastures, Ruzi grass (*Urochloa ruziziensis*), and crop residues (maize stover, rice straw) (Philp et al., 2024). These results established the reference conditions for modeling the effects of feed-based interventions.

2.3.2 Tropical Forages Selection Tool

To identify suitable forage species for the upland systems of Nonghet District, the Tropical Forages: An Interactive Selection Tool (Cook et al., 2020) was applied. The tool is designed to support evidence-based forage selection by combining a comprehensive species database with a filtering system that matches site-specific conditions.

Our methodology involved a stepwise filtering process. Beginning with all 172 species in the database, we applied criteria derived from the agroecological characteristics and management objectives of Nonghet:

1. **Intended forage use:** long-term pasture (>4 years), cut-and-carry, conservation (hay, silage), intercropping, ground cover, agroforestry, and land rehabilitation.
2. **Latitude × altitude:** tropics, 1,000–2,000 m a.s.l.
3. **Soil texture:** medium (loam to clay loam).
4. **Soil fertility:** low to medium.
5. **Soil pH:** strongly acidic (< 5.0) and acidic (5.0–6.5).
6. **Soil drainage:** well-drained to moderately drained.
7. **Average annual rainfall:** 1,500–2,000 mm.
8. **Soil salinity:** low.
9. **Available soil Al/Mn levels:** high.
10. **Plant family:** grass and forage shrubs.
11. **Life cycle:** perennial.
12. **Defined dry season:** up to 6 months.
13. **Inundation duration:** less than 1 week.

This process shortlisted seven suitable forage species. The *Urochloa hybrids* (formerly known as *Brachiaria hybrids*), which include varieties such as Mulato II, Cayman, and Camello, emerged as the most promising group due to their renowned adaptability to acidic, low-fertility soils and capacity to maintain productivity during dry periods. For the purpose of this environmental assessment, which aims to quantify the trade-offs between the baseline and intervention scenarios, *Urochloa hybrid Cayman* (*Urochloa brizantha × U. decumbens* BR02/1752) was selected as a representative candidate. According to fact sheets from Tropical Seeds (2024) and TropicalForages.info, Cayman possesses a deep root system and superior drought tolerance, enabling it to achieve up to 60% higher dry matter yield during dry periods compared to alternatives like *Urochloa ruziziensis* (Ruzi grass). Its robust profile makes it a strong model species for evaluating intervention impacts in the Nonghet uplands.

This process shortlisted seven suitable forage species. The *Urochloa* hybrids (formerly known as *Brachiaria* hybrids), which include Mulato II, Cayman, and Camello, emerged as the most suitable group. These hybrids are widely recognized for their tolerance of acidic, low fertility soils, resistance to aluminum toxicity, strong ground cover, and relatively stable biomass production under prolonged dry season conditions.

Among these options, Mulato II is already known and locally produced in parts of Laos and neighboring countries, and therefore be considered a more immediately adoptable choice for farmers in upland systems. However, the purpose of this study is not to prescribe a single "best" forage for immediate scaling, but rather to conduct an ex-ante environmental assessment of feed-based intensification options, including emerging forages that may become relevant under future climate and land use pressures.

For this reason, *Urochloa hybrid Cayman* was selected as the representative improved forage for modeling the intervention scenario. Cayman is a hybrid of *Urochloa ruziziensis* × *U. decumbens* × *U. brizantha*, developed to combine the drought tolerance and persistence of *U. decumbens* with the productivity and nutritive value of *U. brizantha*. According to TropicalForages.info fact sheets (Cook et al., 2020), Cayman exhibits:

- Water-logging tolerance superior to most cultivars
- Drought tolerant; can be sown where annual rainfall is as low as 800 mm yr^{-1}
- Prefers medium-to-high soil fertility
- Low shade tolerance
- Strong regrowth capacity following grazing or cutting
- Up to 60% higher dry matter yield during dry periods compared with Ruzi grass (*Urochloa ruziziensis*) under comparable conditions

These traits make Cayman particularly suitable for assessing potential future pathways of pasture intensification in upland Laos, where dry season feed scarcity, soil degradation, and land competition are expected to intensify. Using Cayman as a model species therefore allows the environmental assessment to explore the upper bounds of productivity gains and associated trade-offs, while remaining grounded in a forage type that is agronomically plausible for the region.

In addition to grasses, the Tropical Forages Selection Tool also shortlisted woody forage legumes, notably Gliricidia (*Gliricidia sepium*), under the same filtering criteria. Gliricidia is well adapted to tropical upland environments and is widely used in Southeast Asia for living fences, fodder, agroforestry systems, and soil rehabilitation.

Gliricidia's inclusion aligns with the intervention focus on silvopastoral practices, particularly for Type 1 and Type 4 farms. The species offers multiple functional benefits, including high protein fodder, biological nitrogen fixation, erosion control on sloping land, and provision of shade. Its compatibility with cut-and-carry feeding, hedgerows, and living fences makes it a complementary component to Urochloa-based pasture improvements.

2.3.3 CLEANED Tool

The Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment, and Sustainable Development (CLEANED) is a rapid, minimum-data, ex-ante environmental assessment tool developed by the Alliance of Bioversity International and CIAT and ILRI. CLEANED evaluates the potential impacts of livestock interventions on key environmental dimensions including land use, greenhouse gas (GHG) emissions, water use, and productivity (Notenbaert et al., 2020).

The model estimates environmental footprints and helps identify trade-offs between productivity improvements and environmental outcomes. In this study, CLEANED was used to simulate and compare baseline and intervention scenarios for Type 1 and Type 4 farm types.

2.3.4 Diversity for Restoration (D4R) Tool

To complement forage selection, the Diversity for Restoration (D4R) tool was used to identify tree species suited for silvopastoral practices with primarily living fences, fodder trees, and shade trees. Developed by Bioversity International, the D4R platform (https://www.diversityforrestoration.org/) supports species selection.

The selection process focused on traits required for upland livestock systems in Nonghet, including tolerance to acidic soils, rapid regrowth after pruning, compatibility with cut-and-carry use, soil fertility enhancement, and resilience under a 5–6-month dry season. Climatic and edaphic filters were aligned with Nonghet's monsoon climate, elevation (1,200–1,500 m a.s.l.), strongly acidic soils, and low soil fertility conditions.

Based on these criteria, *Gliricidia sepium* was identified as an optimal species for both Type 1 and Type 4 interventions. *Gliricidia* enhances the productivity and resilience of forage systems while supporting soil rehabilitation and climate-smart livestock production. For these reasons, *Gliricidia sepium* was incorporated into the silvopastoral intervention package for both farm types.

2.4 Intervention Scenario

Intervention scenarios were designed to evaluate how forage-based interventions and integrated land management practices could enhance livestock productivity and environmental outcomes in Nonghet District. Two representative farm types: Type 1 (Extensive mixed farms with greater pasture orientation) and Type 4 (Semi-intensive upland mixed farms) were selected based on their dominance in the region and contrasting production intensities.

Improvements in Type 1 and type 4 are primarily driven by enhanced forage quality, dry season feed stability, and adoption of silvopastoral practices. Key factors include:

- Replacement of Ruzi grass with Cayman, which offer substantially higher dry-matter yields, better drought tolerance, and high nutritive value, improving growth rates and reducing seasonal feed gaps.
- Incorporation of *Gliricidia* as a fodder tree, providing a high-protein supplement that supports rumen function, increases liveweight gain, and supplies feed during dry season bottlenecks.
- Silvopastoral integration including living fences, shade trees, and fodder shrubs which improves pasture microclimates, reduces heat stress, enhances manure distribution, and stabilizes forage production on sloping land.
- Use of silage (maize + Cayman) for stall-fed bulls, offering a stable and energy dense feed source that improves rumen efficiency and supports more consistent growth throughout the dry season.
- Improved pasture structure through reduced pressure on natural grazing areas, enhancing ground cover, reducing erosion risk, and promoting more sustainable stocking rates over time.

Together, these interventions strengthen feed reliability, reduce environmental degradation, and enhance productive potential without altering herd structure.

2.4.1 Extensive Mixed Farms with Greater Pasture Orientation (Type 1)

Type 1 represents large, livestock-oriented farms where grazing dominates land use. Herds average about 30 cattle, with additional adult males, steers/heifers, and fighting bulls. Farmers rely heavily on natural pastures and Ruzi grass (*Urochloa ruziziensis*), with minimal supplementation. Landholdings average 30 ha, of which around 23 ha are used for grazing.

Feed scarcity during the dry season leads to slow growth rates and land degradation from overgrazing. Below is the changes in feed basket between baseline and intervention scenarios for rainy and dry seasons

Table 3. Feed basket composition in Type 1 in rainy and dry season for both baseline and intervention scenarios

Rainy season

Feed item	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)
	Bull		Cattle		Pigs	
Ruzi grass			100			
Napier grass	90					
Cayman		100		80		
Maize stover	10				30	30
Rice bran					70	70
Gliricidia				20		
Total	**100**	**100**	**100**	**100**	**100**	**100**

Dry season

Feed item	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)
	Bull		Cattle		Pigs	
Natural pasture / grazing	90					
Ruzi grass			100			
Cayman		50		80		
Maize stover	10				30	30
Rice bran					70	70
Silage (70% maize + 30% Cayman)		50				
Gliricidia				20		
Total	**100**	**100**	**100**	**100**	**100**	**100**

2.4.2 Type 4: Semi-Intensive Upland Mixed Farms

Type 4 systems integrate livestock, maize, and rice within 5–10 ha farms. Herds average 10 cattle and 2–3 pigs. Cattle are partly stall-fed with crop residues and natural grasses, while pigs contribute to diversified income. The system faces land scarcity but higher feed efficiency and potential for crop–livestock integration. Below is the changes in feed basket between baseline and intervention scenarios for rainy and dry seasons

Table 4. Feed basket composition in Type 4 in rainy and dry season for both baseline and intervention scenarios

Rainy season

Feed item	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)
	Bull		Cattle		Pig	
Ruzi grass			100			
Napier grass	80					
Cayman		100		80		
Maize stover	20				40	40
Rice bran					60	60
Gliricidia				20		
Total	**100**	**100**	**100**	**100**	**100**	**100**

Dry season

Feed item	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)	Baseline (%)	Intervention (%)
	Bull		Cattle		Pig	
Natural pasture / grazing	80					
Ruzi grass			100			
Cayman		50		80		
Maize stover	20				40	40
Rice bran					60	60
Silage (70% maize + 30% Cayman)		50				
Gliricidia				20		
Total	**100**	**100**	**100**	**100**	**100**	**100**

Results

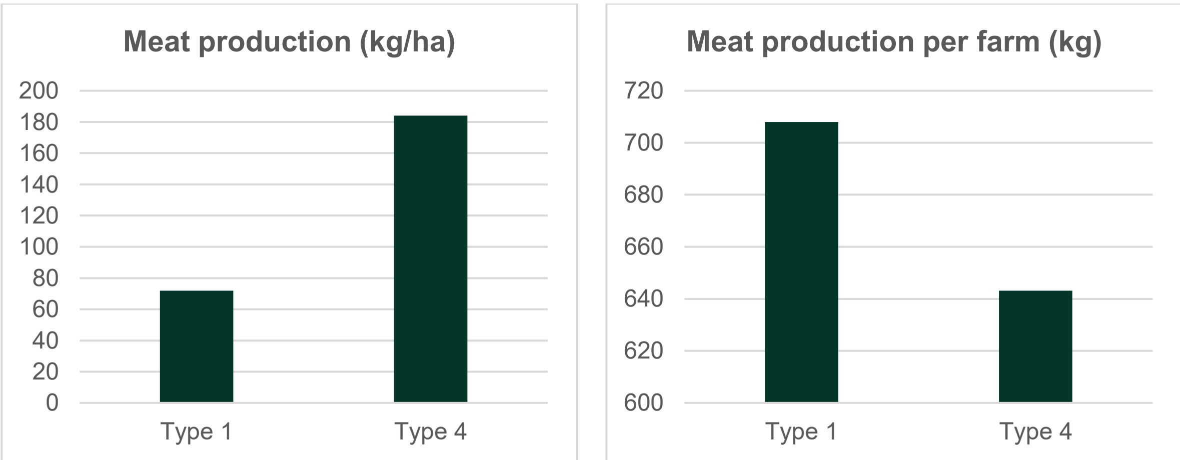
3.1 Intervention scenario results

3.1.1. Meat production

Type 1 farms operate on a large land base of 30 ha, supporting a predominantly cattle-oriented system with 30 cows, 6 adult males, 6 steers/heifers, 6 calves, 2 fighting bulls, and 4 grower pigs. Under the intervention, improved pastures with *Urochloa hybrid cv. Cayman* and supplemental *Gliricidia* strengthen forage supply across seasons, enhancing the nutrition of a sizeable ruminant herd. Meat production reaches 71.82 kg/ha, totaling 708 kg per farm, reflecting the system's extensive scale and the high biomass productivity of improved forages.

Type 4 farms manage a smaller and more diversified herd with 4 cows, 2 adult males, 5 steers/heifers, 4 calves, 1 fighting bull, 3 dry sows/boars, and 8 pigs within only 5 ha. The intervention enables these systems to achieve 184.08 kg of meat per hectare, amounting to 643.2 kg per farm, reflecting highly efficient land use and the stronger integration of improved forages, processed maize stover, and targeted supplementation for bulls. Despite their smaller scale, Type 4 farms show strong production performance per hectare due to better feed conversion and more controlled management.

Figure 1. Meat production of type 1 and type 4 in intervention scenario

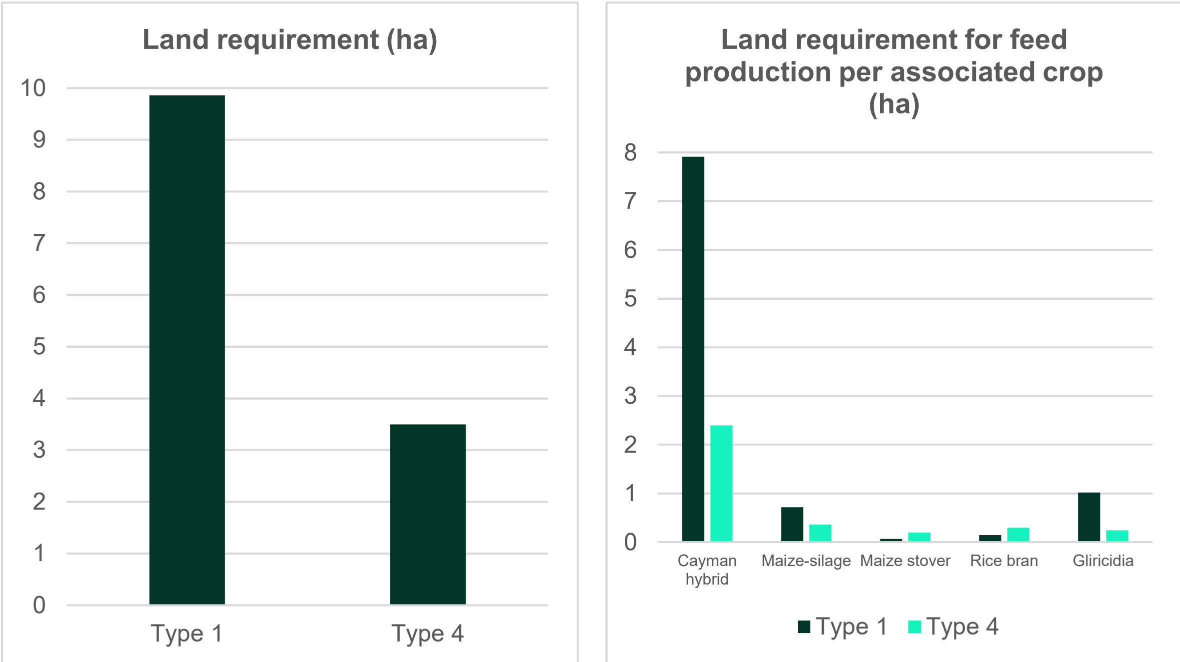


3.1.2 Land use requirements

The interventions reduce the land area for type 1 needed to sustain livestock feed production to 9.86 ha, reflecting the higher productivity of improved forages relative to native vegetation or Ruzi grass. Despite the large herd size, high-yield perennial grasses *Urochloa hybrid cv. Cayman* and *Gliricidia* allow better use of the existing 30 ha farm area by reducing pressure on natural grazing land, improving rotational management, and stabilizing forage supply throughout the year.

Feed production for Type 4 requires only 3.49 ha, demonstrating the high land-use efficiency of semi-intensive mixed farming systems. The combination of *Urochloa hybrid cv. Cayman* pastures, maize residues, and *Gliricidia* hedgerows allow for intensified production within a limited area. This efficient use of land reduces grazing pressure and supports sustainable forage crop integration on small upland plots.

Figure 2. Land use requirements of type 1 and type 4 in intervention scenario

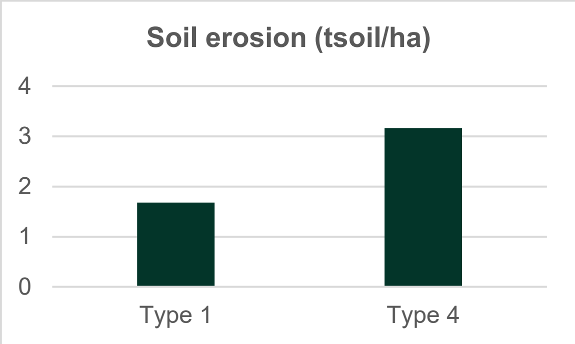


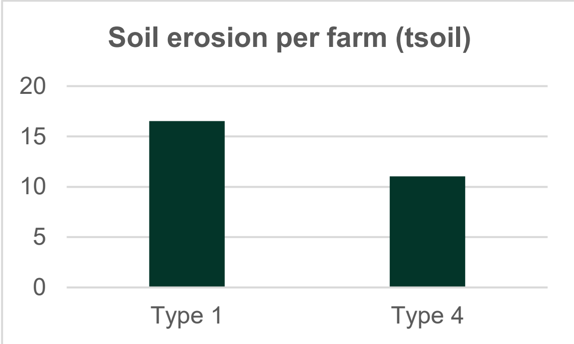
3.1.3 Soil and nutrient dynamics

The environmental assessment in type 1 shows an N balance of –164.84 kg/ha, illustrating substantial nutrient export through biomass consumption and limited nutrient return to soils. This is typical for extensive systems with large cattle herds and minimal manure recycling. Soil erosion declines to 1.68 t/ha (16.52 t per farm), which reflects the soil-stabilizing effect of *Urochloa* stands and the presence of *Gliricidia* living fences.

In type 4, the nutrient balance is –148.76 kg/ha, indicating substantial nutrient removal due to high forage harvesting and limited nutrients cycling back to the soil, which is common in smallholder systems with limited manure redistribution. Soil erosion falls to 3.16 t/ha (11.05 t per farm), driven by the soil protective effects of perennial grasses and improved ground cover. Although erosion per hectare is higher than Type 1, total erosion per farm is substantially lower because of the small land size. Improved forage cover helps stabilize sloping land typical of upland districts.

Figure 3. Soil erosion of type 1 and type 4 in intervention scenario





3.1.4 Climate and water impacts

Type 1 farms generate 189.73 kg CO_2eq per kg of meat, driven primarily by enteric fermentation from the large number of ruminants. GHG emission intensity at the land scale reaches 13.1 t CO_2eq/ha, consistent with extensive cattle dominant systems. Carbon stock change remains slightly negative (–0.18 t CO_2-eq/ha), reflecting steady soil carbon turnover despite improved forage cover. Water use is 44.53 m^3/kg of meat, totaling 31,530 m^3 per farm, shaped by the substantial water demand of a large cattle herd across a 30 ha system. Although forage efficiency improves, herd size remains the dominant influence on water use.

GHG emissions in type 4 reach 68.06 kg CO_2eq per kg of meat, substantially lower than Type 1 due to the smaller ruminant population and better feed conversion efficiency. However, land based emission intensity stands at 12.53 t CO_2eq/ha, reflecting concentrated production on small plots. Carbon stock change is slightly negative (–0.15 t CO_2eq/ha), similar to Type 1, showing consistent but modest turnover in soil organic matter. Water use is efficient at 16.85 m^3/kg meat, with 10,838 m^3 per farm, reflecting smaller herd size and more efficient conversion of forage biomass into animal product within a semi-intensive system.

Figure 4. Greenhouse emissions of type 1 and type 4 in intervention scenario

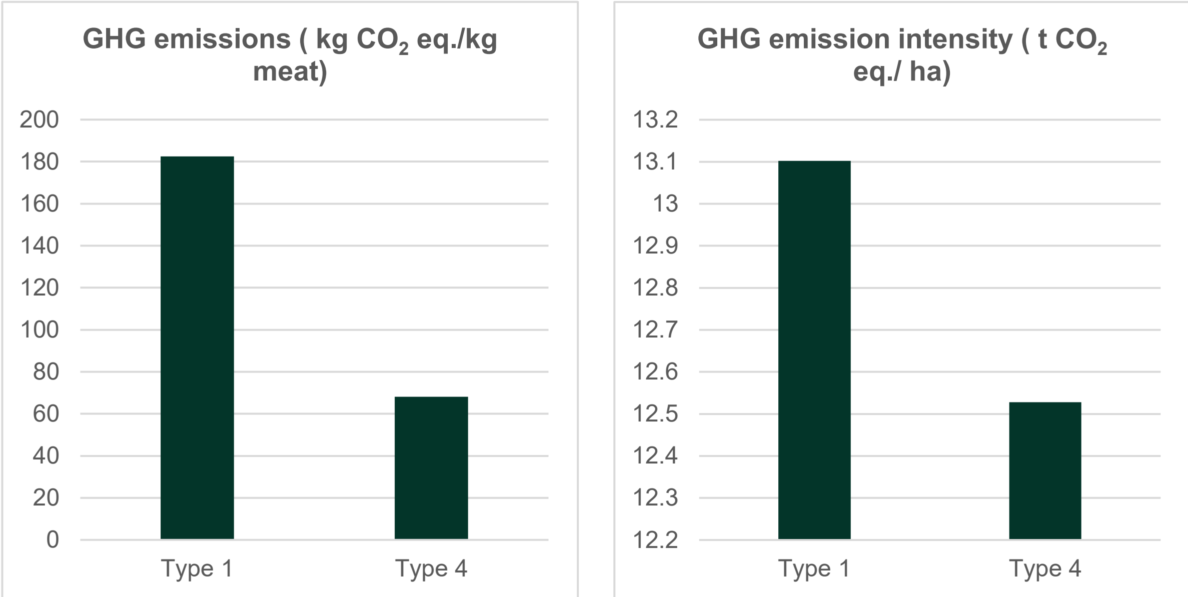
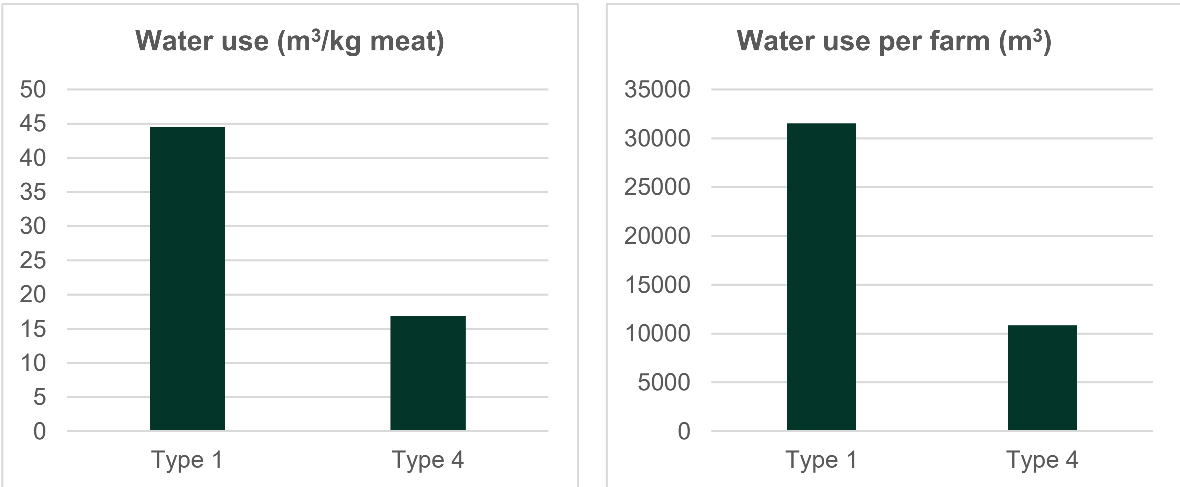


Figure 5. Water use of type 1 and type 4 in intervention scenario



3.2 Trade-offs in environmental impacts

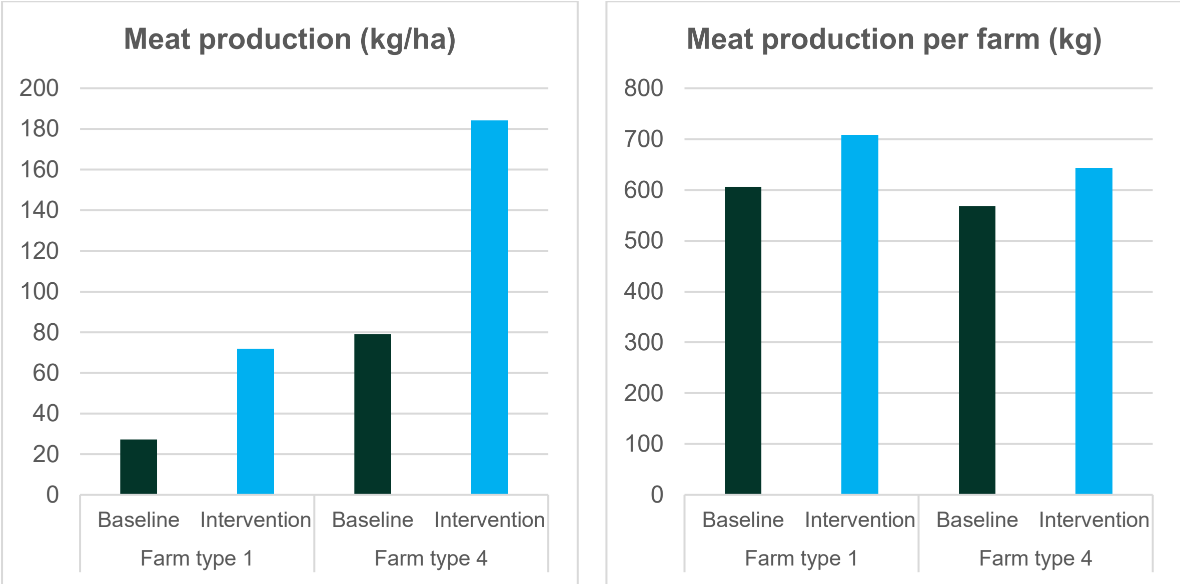
3.2.1 Production impacts

Type 1: Extensive livestock-oriented systems

Type 1 showed a strong positive response to the introduction of *Urochloa hybrid cv. Cayman* and silvopastoral practices. Meat production per hectare increased from 27.25 kg/ha under the baseline to 71.82 kg/ha with the intervention. This increase reflects both higher forage availability during the dry season and improved feed quality throughout the year, which together support better growth rates in cattle and stall-fed bulls.

Meat production per farm also increased, though to a lesser extent, rising from 606 kg to 708 kg per farm (~17% increase). The moderate gain at farm scale is expected, as herd size remains constant. These results indicate that even without increasing livestock numbers, nutritional upgrading can deliver meaningful productivity benefits while easing grazing pressure on natural pastures.

Figure 6. Production characteristics of farm type 1 and type 4 in baseline and intervention scenarios



Type 4: Semi-Intensive Mixed Farms (Crop–Livestock Integrated)

Type 4 exhibited even larger productivity gains from the intervention scenario. Meat production per hectare rose from 78.96 kg/ha to 184.08 kg/ha, a 133% increase, attributable to the combined effects of higher-quality forage (*Urochloa hybrids*), improved grazing management, and enhanced utilization of silage maize stover in the feed.

At the farm level, meat output increased from 568 kg to 643.2 kg, equivalent to a 13% improvement. The smaller proportional increase at the farm scale reflects the relatively balanced baseline feed system in Type 4 farms, which were already semi-intensive.

3.1.2 Environmental impacts

Table 5. Environmental and climate impacts of farm type 1 and type 4 in baseline and intervention scenarios

	Farm Type T1		Farm Type T4	
	Baseline	**Intervention**	**Baseline**	**Intervention**
Land requirement (ha)	22.23	9.86	7.19	3.49
N balance (kg/ha)	-58.46	-164.84	-60.42	-148.76
Soil erosion (tsoil/ha)	4.72	1.68	5.51	3.16
Soil erosion per farm (tsoil)	105.03	16.52	39.62	11.05
GHG emissions (kg CO_2 eq. /kg meat)	178.01	182.43	65.26	68.06
GHG emission intensity (t CO_2 eq. / ha)	4.85	13.10	5.15	12.53
Balance GHG emissions - C-stock change (tCO_2e /ha)	5.05	13.28	5.32	12.68
Water use (m^3/kg meat)	55.48	44.53	23.08	16.85
Water use per farm (m^3)	33,622.20	31,530.34	13,109.89	10,837.64

Table 6. Environmental trade-offs of interventions

Farm types	Production		Land	Soil impacts	Water impacts		GHG emissions	
	meat produced (kg/year)	Meat produced (kg/ha/year)	ha/yr	Erosion (t soil/yr)	m^3/year	m^3/kg meat	t CO2eq./year	kg CO2 eq. /kg meat
T1	16.83%	163.50%	-55.66%	-84.27%	-6.22%	-19.73%	19.73%	2.48%
T4	13.24%	133.14%	-51.43%	-72.12%	-17.33%	-27.00%	18.08%	4.28%

Farm types	Production		Land requirements	Soil impacts	Water impacts		GHG emissions	
	meat produced (kg/year)	Meat produced (kg/ha/year)	ha/yr	Erosion (t soil/yr)	m^3/year	m^3/kg meat	t CO2eq./year	kg CO2 eq. /kg meat
T1	+	+++	++	++	+	+	-	-
T4	+	+++	+	++	+	+	-	-

Legend (%)	
+++	< - 109
++	-55 to -109
+	0 to -55
	0
-	0 to 55
--	5 to 109
---	> 55

Best case scenario

No effect

Worst case scenario

A relative change (%) from the baseline environmental footprint was calculated for each indicator, and results were summarized using a colour-coded matrix and a symbol system to show the direction and magnitude of environmental change. The “+” signs represent improvements compared with baseline conditions, while the “–” signs indicate a worsening of the environmental condition. The intensity of change is proportional to the number of signs:

+++ / --- = very large improvement or deterioration

++ / -- = moderate improvement or deterioration

+ / - = small improvement or deterioration

These categories were derived from uniform percentage intervals based on the maximum observed change, allowing consistent interpretation across indicators.

Type 1: Extensive livestock-oriented systems

For Type 1 farms, the intervention scenario delivers substantial gains in land use efficiency and soil conservation, while revealing clear trade-offs related to nutrient balance and greenhouse gas (GHG) emissions. The introduction of high-yield perennial forages, notably *Urochloa hybrid cv. Cayman*, together with *Gliricidia* in silvopastoral arrangements, sharply reduces the land area required to sustain the existing herd. Feed production land requirements fall from 22.23 ha to 9.86 ha per farm, representing a strong improvement in land productivity ("++" in the trade-off matrix). This reduction reflects higher dry matter yields per hectare and a shift away from degraded natural pastures and Ruzi grass.

Soil erosion indicators show the most pronounced positive response. Erosion rates decline from 4.72 to 1.68 t soil/ha, while total soil loss per farm drops from 105.03 to 16.52 t, corresponding to a very large improvement ("+++").

Production performance also improves markedly. Meat output per hectare increases strongly ("+++"), reflecting better feed quality, improved dry-season feed availability, and more consistent intake under stall-feeding and cut-and-carry systems. Meat production per farm increases more modestly ("+"), as herd size is held constant by design. These results confirm that productivity gains are achieved through improved feed efficiency rather than herd expansion.

However, these benefits are accompanied by important environmental trade-offs. The nitrogen balance becomes substantially more negative, declining from –58.46 to –164.84 kg N/ha, indicating intensified nutrient extraction by high-yield forages without compensatory nutrient inputs. This is a clear signal of potential soil fertility mining if improved feed systems are scaled without integrated soil fertility management. Greenhouse gas emissions also increase on an area basis, rising from 4.85 to 13.1 t CO_2e/ha, and emissions per kilogram of meat increase slightly from 178.01 to 182.43 kg CO_2e/kg meat, reflected as a negative change ("–") in the trade-off matrix. These increases are linked to higher biomass turnover and greater enteric emissions associated with improved feed intake, while carbon stock gains remain limited.

Water-related indicators show a mixed but generally favorable pattern. Water use per kilogram of meat improves from 55.48 to 44.53 m^3/kg, reflecting more efficient conversion of water into animal product ("+"), while total water use per farm declines slightly from 33,622 to 31,530 m^3 due to reduced land area under forage. Overall, Type 1 interventions deliver strong synergies for land degradation control and water-use efficiency but require complementary nutrient management strategies and careful consideration of GHG mitigation options.

Type 4: Semi-Intensive Mixed Farms (Crop–Livestock Integrated)

Type 4 farms exhibit a more balanced set of synergies and trade-offs under the intervention scenario, reflecting the smaller land, semi-intensive management, and stronger crop–livestock integration. Land requirements for feed production decline from 7.19 to 3.49 ha per farm, corresponding to a substantial improvement in land use efficiency ("++"). This outcome is driven by the combined use of *Urochloa* hybrid pastures, processed maize stover, silage for stall-fed bulls, and *Gliricidia* hedgerows, which together support higher feed output per unit area.

Soil conservation benefits are again very strong. Soil erosion decreases from 5.51 to 3.16 t/ha, and total soil loss per farm falls from 39.62 to 11.05 t, representing a very large improvement ("+++"). The establishment of perennial forages and legumes provides continuous soil cover, which is particularly important given the steeper slopes and smaller parcel sizes typical of Type 4 farm.

Production indicators show robust positive responses. Meat output per hectare increases strongly (“+++”), reflecting improved feed quality, better utilization of crop residues through silage, and reduced seasonal feed gaps. As with Type 1, herd size remains unchanged, so productivity gains stem from improved feed efficiency rather than herd expansion.

Environmental trade-offs are present but less pronounced than in Type 1. The nitrogen balance becomes more negative, shifting from –60.42 to –148.76 kg N/ha, again highlighting increased nutrient demand under higher-yield forage systems. GHG emissions increase moderately: emissions per hectare rise from 5.15 to 12.53 t CO_2e/ha, and emissions per kilogram of meat increase slightly from 65.26 to 68.06 kg CO_2e/kg meat, classified as a small negative change (“–”). These increases are associated with higher feed intake and greater on-farm biomass cycling, though the magnitude of deterioration is smaller than in the extensive Type 1 systems.

Water indicators reveal important synergies. Water use per kilogram of meat improves markedly from 23.08 to 16.85 m^3/kg, indicating more efficient water productivity under integrated feed systems. Total farm water use also declines from 13,109 to 10,838 m^3, reflecting reduced land area under forage and more efficient feed conversion. This combination of improved water-use efficiency and reduced erosion makes the intervention particularly attractive for small upland farms facing seasonal water stress.

Conclusions

This assessment demonstrates that introducing improved forage systems, particularly *Urochloa hybrids*, and silvopastoral elements such as *Gliricidia* can substantially enhance the productivity and environmental performance of upland livestock systems. For both Type 1 (extensive pasture-oriented farms) and Type 4 (semi-intensive upland mixed farms), the intervention scenario achieved strong gains in meat productivity per hectare, driven by improved dry season feed availability, higher forage quality, and more efficient nutrient use. These productivity gains translated into significant reductions in land requirements, indicating that sustainable intensification can reduce pressure on communal grazing areas and mitigate land degradation in upland landscapes.

Environmental co-benefits were most evident in soil conservation. Soil erosion declined sharply in both types, reflecting the stabilizing role of perennial grasses and legumes under improved grazing and cut and carry systems. These findings underscore the importance of integrating improved forages and tree components into sloping agricultural systems. Water use efficiency per unit of output also improved, particularly in Type 4 systems, despite slight increases in total water demand associated with forage production. As expected, greenhouse gas emissions per hectare and per kilogram of meat increased moderately under both types, reflecting higher animal intake and nutrient turnover.

The results show that targeted feed and forage interventions can deliver meaningful improvements in productivity, land use efficiency, and erosion control in upland Laos, while presenting manageable climate-related trade-offs. These findings support the case for promoting diversified, forage-based livestock systems integration trees as a pathway toward more resilient, productive, and environmentally responsible livestock development in the uplands.

Policy Recommendations

1. **Prioritize investment in improved forages for upland livestock systems**

Government and development programs should incentivize the adoption of high-yield, drought-tolerant perennial forages such as *Urochloa hybrids* (Cayman, Camelo/Mulato II) to address persistent dry-season feed shortages. These forages have demonstrated large gains in land use efficiency and soil protection, and can significantly reduce grazing pressure on fragile sloping areas.

2. **Promote silvopastoral practices**

The integration of fodder trees, living fences, and shade species such as *Gliricidia leucocephala* should be mainstreamed into upland livestock development programs. These systems deliver substantial erosion control benefits, improve microclimate for animals, and enhance long term soil fertility through nitrogen fixation and biomass recycling.

3. **Support smallholders in adopting forage–maize integration and silage technologies**

Maize stover processing and silage production show strong potential for Type 4 semi-intensive farms, improving nutrient use efficiency and reducing seasonal feed gaps. Policy support should include training, extension services, and access to small scale silage equipment to enable wider adoption.

4. **Strengthen land use planning to capitalize on reduced land demand for feed**

Since improved forages significantly reduce land requirements for livestock, policies should encourage the rehabilitation of bare land through agroforestry, food crop diversification, or ecological restoration. These should be supplemented with appropriate incentive mechanisms to reward ecosystem service provision that contributes to national goals on forest cover, erosion reduction, and climate mitigation.

5. **Mitigate GHG trade-offs through manure management and improved herd structure**

Because intensification increases herd level methane and manure emissions, complementary interventions such as improved manure handling, composting, strategic herd restructuring, as well as silvopastoral practices that increase farm carbon stocks, should be supported. These measures can offset the moderate rise in emission intensities seen under the intervention scenario.

6. **Develop localized decision-support tools and advisory systems and strengthen farmer training**

The use of GFEAST, TropicalForages.info, and CLEANED in this study demonstrates the value of decision-support tools for identifying suitable forages and evaluating system-wide trade-offs. National and provincial programs should integrate these tools into extension programs to help farmers and planners make informed, site-specific decisions.

7. **Expand future analyses to include economic performance and cost–benefit analysis**

Future research should extend the application of the CLEANED framework to incorporate economic indicators, including investment costs, operating costs, and returns from improved productivity. By enabling cost–benefit analysis of baseline and intervention scenarios, CLEANED could support more comprehensive evaluations of adoption feasibility, profitability, and trade offs between environmental and economic outcomes, thereby strengthening its relevance for policymakers, donors, and farmers.

References

Cook BG; Pengelly BC; Schultze-Kraft R; Taylor M; Burkart S; Cardoso Arango JA; González Guzmán JJ; Cox K; Jones C; Peters M. (2020). Tropical Forages: An interactive selection tool. 2nd and Revised Edn. International Center for Tropical Agriculture (CIAT), Cali, Colombia and International Livestock Research Institute (ILRI), Nairobi, Kenya. www.tropicalforages.info

Dao Thu, H. T., Notenbaert, A., Philp, J., & Atieno, M. (2025a). *Environmental Footprints of Livestock Production Systems in Northern Laos: Baseline Report.* CGIAR/CIAT. https://hdl.handle.net/10568/173901

Guillaume, L., Jeremy, B., Bounthanom, B., Jean-Christophe, C. (2011), Measuring participation: Case studies on village land use planning in northern Lao PDR, Applied Geography, Volume 31, Issue 3, 2011, Pages 950-958, ISSN 0143-6228, https://doi.org/10.1016/j.apgeog.2011.01.003.

Notenbaert, A., van der Hoek, R., Mwema, E., Mukiri, J., & Paul, B. (2022). CLEANED: A tool for flagging and addressing environmental issues in livestock production systems. Nairobi, Kenya: International Center for Tropical Agriculture (CIAT). https://hdl.handle.net/10568/125794

Philp, J. N. M., Soytavanh, M., Atieno, M., Jalonen, R., Mekonnen, K., Gebreyes, M., & Peters, M. (2024). *Evaluation of Feed Resource Availability and Use for Sustainable Livestock Production in the Northern Highland Systems of Lao PDR.* 19 p. https://hdl.handle.net/10568/163593

Phouyyavong, K., Tomita, S., & Yokoyama, S. (2019): *Impact of forage introduction on cattle grazing practices and crop–livestock systems: a case study in an upland village in northern Laos.* The Rangeland Journal, 41(4), 323–334. https://doi.org/10.1071/RJ18102

Tropical Seeds. (2024). *Brachiaria (Urochloa) Hybrid Forages – Cayman®, Camelo®, and Mulato II®.* https://www.tropseeds.com/

Vongvisouk, T., Mertz, O., Thongmanivong, S., Heinimann, A., & Phanvilay, K. (2014). Shifting cultivation stability and change: Contrasting pathways of land use and livelihood change in Laos. *Applied Geography, 46*, 1-10. https://doi.org/10.1016/j.apgeog.2013.10.006

Zepeda A, Mponela P, Phimmachanh P, Louanhsakha T., Phaphoungern P., Tiemann T, Krupnik T.J., and Lopez-Ridaura S. (2025). Characterizing highland maize-mixed farming systems of Lao´s PDR's Xiengkhouang Province (Kham, Moke, Nonghet): statistical analysis and participatory validation. CGIAR research initiative on Mixed Farming Systems (MFS). International Maize and Wheat Improvement Center. Vientiane, Laos PDR. https://cgspace.cgiar.org/server/api/core/bitstreams/6aef4298-7c18-41de-ba87-bc388e872ab9/content

Link to Decision-Support tools:

1. Gendered feed assessment tool (G-FEAST): https://gender.cgiar.org/tools-methods-manuals/gendered-feed-assessment-tool-g-feast
2. Tropical Forages selection tool: https://tropicalforages.info/text/intro/index.html

3. Comprehensive Livestock Environmental Assessment for Improved Nutrition, a Secured Environment, and Sustainable Development (CLEANED): https://alliancebioversityciat.org/tools-innovations/cleaned
4. D4R Tool (Diversity for restoration): https://www.diversityforrestoration.org/


Acknowledgements

This work was conducted as part of the CGIAR Sustainable Farming (SF) Science Program, with contributions from the ASEAN-CGIAR Innovate for Food and Nutrition Security Regional Program, and Sustainable Animal and Aquatic Foods (SAAF) Science Programs and Accelerators. CGIAR research is supported by contributions to the CGIAR Trust Fund. CGIAR is a global research partnership for a food-secure future dedicated to transforming food, land, and water systems in a climate crisis.

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