BIODIVERSITAS ISSN: 1412-033X
Volume 26, Number 1, January 2025 E-ISSN: 2085-4722
Pages: 73-84 DOI: 10.13057/biodiv/d260108

Enhancing sustainable livestock support through *Kaliwo* agroforestry in Southwest Sumba District, Indonesia

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Manuscript received: 14 October 2024. Revision accepted: 4 January 2025.

Abstract. *Kii WY, Sodiq A, Sumarmono J, Setianto NA, Jelan ZA. 2025. Enhancing sustainable livestock support through* Kaliwo *agroforestry in Southwest Sumba District, Indonesia. Biodiversitas 26: 73-84.* The agroforestry system is one of the most popular land management systems related to livestock production. The objectives of this study were to establish the roles of *Kaliwo* agroforestry and its interconnections with the livestock production system as a source of animal feed, a free-range habitat for poultry such as chickens and ducks, and sources of local materials for the construction of livestock enclosures within the Southwest Sumba District, Indonesia. The research used a qualitative descriptive method involving 420 farmers. We collected data using questionnaires, Focus Group Discussions (FGDs), and direct observation in three agro-ecosystem zones: lowland (Loura and Kodi) and highland (Wewewa). The triangulation method validated the data obtained from interviews, observations, and FGDs. We performed the descriptive analysis using both statistical and non-statistical methods. The findings indicated that farmers procured 18 species of forage from *Kaliwo* as feed for both ruminants (goats, buffaloes, and cattle) and non-ruminants (pigs and horses), particularly during the dry season when forage in pastures was scarce. Furthermore, *Kaliwo* serves as a free-range environment for poultry and livestock, including pigs and goats in Loura, and it constitutes the main source of materials for the construction of livestock pens. Farmers repurpose residual fodder and manure as organic fertilizer for a variety of crops cultivated in *Kaliwo* and small farms. *Kaliwo* is considered one of the key resources in livestock production systems for its long establishment and favourable adaptation to the natural environment. The integration of agroforestry practices with livestock husbandry can serve as a paradigm for sustainable livestock farming by leveraging local ecological wisdom.

Keywords: Agriculture livestock integration, *Kaliwo* agroforestry, traditional livestock production

INTRODUCTION

Traditional Agroforestry Systems (TAS) are established methodologies that integrate agriculture, plantation, and forestry. These systems have been employed in tropical regions, including Asia, Africa, South America, and the Pacific Islands, since the inception of agricultural practices (Hartoyo et al. 2022). In fact, during the Dutch colonial period, Indonesian farmers have historically engaged in the institutionalized practice of shifting cultivation methods (Achmad et al. 2022), which include but not limited to *Pekarangan* (West Java, a homegarden intercropping system), *Talun* (West Java, mixed tree garden), *Parak* (West Sumatera, combines agricultural practices with forestry) *Repong* (Lampung, integration of various crops and tree species, *Damar* (Lampung, focuses on the cultivation of Damar trees (*Shorea javanica* Koord. & Valeton), *Kebon* (home gardens), and *Kaliwu* (Central Sumba District, home garden) (Njurumana et al. 2021; Parikesit et al. 2021; Briliawan et al. 2022; Ngongo et al. 2022; Octavia et al. 2022).

Traditional agroforestry systems have changed a lot in the last 40 years to focus on ecological aspects that could protect soil and water (Marques et al. 2022), lessen the effects of global warming (Ogunmodede 2020), improve sustainable farming methods (Hasannudin et al. 2022), make marginal lands more productive (Achmad et al. 2022), and boost soil fertility and microbial diversity (Wang et al. 2020; Ngongo et al. 2022). Agroforestry can reduce the negative impacts of monoculture agriculture, such as soil salinity and water pollution due to excessive use of inorganic fertilizers, herbicides, fungicides, and pesticides (Pavlidis et al. 2020; Briliawan et al. 2022). Previous studies have led to models integrating agriculture with medicinal plants, livestock, and fisheries (Octavia et al. 2022) and enhancing farmers' productivity and income (Sudomo et al. 2023).

Farmers have adapted to the climate condition and continued to innovate in their pursuit of agricultural and livestock systems that effectively sustain their livelihoods. Integrating agricultural-livestock production systems, known as *Kaliwo* or *Kaliwu*, is a local wisdom of Sumbanese agriculture and animal husbandry, passed down from generation to generation and still practiced today (Njurumana et al. 2021).

A study on *Kaliwo* (Southwest Sumba dialect) or *Kaliwu* (Central Sumba dialect) indicates that this dryland agroforestry model is capable of yielding significant benefits and serving as a sustainable livelihood for farmers in the region (Njurumana et al. 2021). The Sumbanese people have long practiced the *Kaliwo* agroforestry system, which embodies traditional and customary values related to their social, economic, and ecological systems. However, there is a lack of widely available studies on the role of this system in livestock production.

This study describes the important roles of *Kaliwo* agroforestry and its interconnections with the livestock production system in Southwest Sumba concerning (i) The utilization of *Kaliwo* agroforestry as a location of forage feed of ruminants (goats, buffaloes, and cattle) and non-ruminants (pigs and horses), particularly during the dry season when forage availability in grazing lands is alarmingly limited; (ii) The function of *Kaliwo* agroforestry as a free-range livestock rearing environment and (iii) The provision of materials from *Kaliwo* agroforestry for the construction of livestock facilities and traditional dwelling structures (including bamboo, alang, trees, and rattan rope). The findings derived from this study serve as a basis for developing strategies to enhance livestock production in *Kaliwo* agroforestry.

MATERIALS AND METHODS

Study area

Sumba Island is located along the Wallace and Weber imaginary lines that distinguish species in Australia, Papua New Guinea, and Southeast Asia. A stark difference is particularly evident among mammals between Australia and Papua New Guinea and the Southeast Asia region. The actual climatic condition profoundly influences the cultural practices of agricultural land management and livestock husbandry in the Southwest Sumba District, Indonesia, situated between latitudes 9° 18' and 10° 20' South and longitudes 118° 55' and 120° 23' East, served as the site for the study conducted from November 2022 to July 2023. The district covers hilly areas of 1,445.32 km², which in 2023, comprised 11 sub-district, 175 villages, and two urban villages (Figure 1). The elevation ranges between the lowland (0-400 masl), such as Loura and Kodi, and the highland (100-800 masl), as in Wewewa. Lede Kalumbang Airport Meteorological Post in 2023 reported that the lowest and highest air temperatures in the district were 16°C (August) and 35.2°C (November and December), respectively, with an average of 24.2-29.1°C. The highest rainfall was 332.7 mm³ in February, with an average of 152 rainy days per annum (BPS 2024).

Data collection

We selected the agro-ecosystem zones in the administrative area of Southwest Sumba District (BPS 2024) through purposive sampling, taking into account the characteristics of the agro-ecosystem, precisely the expanse of agricultural lands, plantations, and pastures: (i) The lowland agro-ecosystem in the distinctive lowland topography (e.g., savanna, limestone or karts soil, and shallow soil strata) in two sub-districts of Loura and Tambolaka. It is characterized by a dry climate and minimal precipitation in three to four rainy months, from December to March. (ii) The lowland agro-ecosystem in the temperate lowland comprises four sub-regencies: Kodi, North Kodi, Kodi Bangedo, and Kodi Balaghar. The agricultural soil layer in Loura and Wewewa is the most fertile despite having a slight limestone layer. The rainfall in this area is 4-5 months/year from November to March. (iii) The highland agro-ecosystem is located in a hilly terrain area of the Wewewa area, encompassing five sub-districts: West Wewewa, South Wewewa, East Wewewa, Central Wewewa, and North Wewewa. It has a humid climate and rainfall over 5 to 7 months, from October to May.

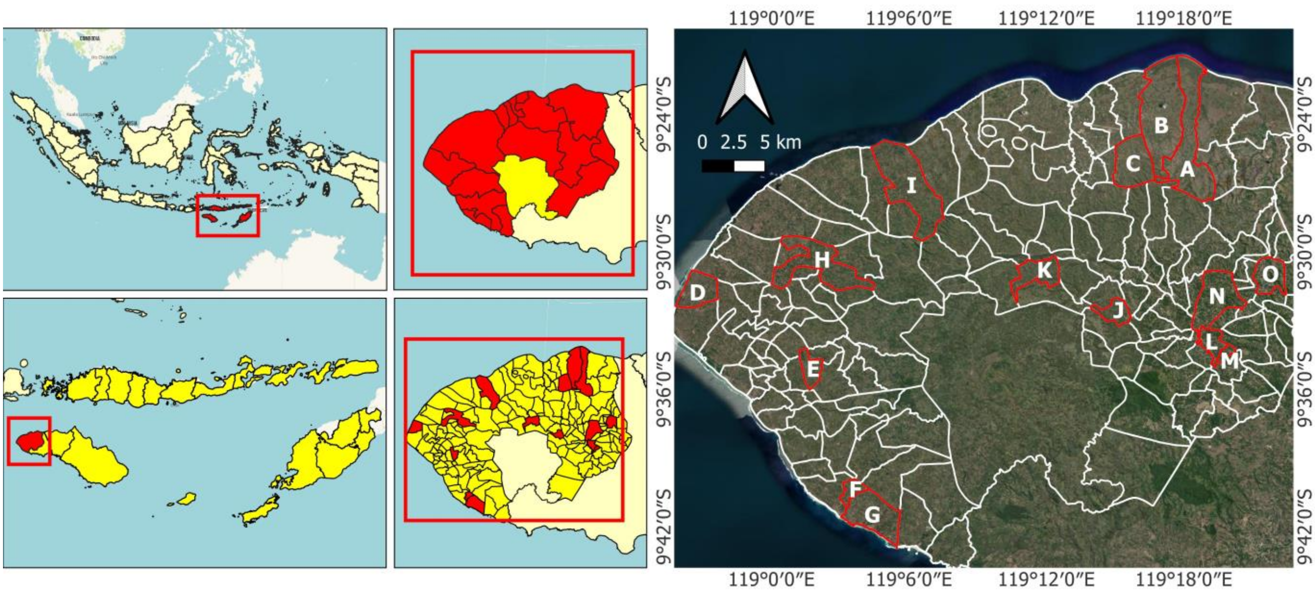

Figure 1. Administrative area of Southwest Sumba District, Indonesia: A. Karuni; B. Rama Dana; C. Wee Pangali; D. Tanjung Karoso; E. Rada Loko; F. Tana Mete; G. Panenggo Ede; H. Kori; I. Bukambero; J. Kalembu Kanaika; K. Kalembu Weri; L. Kalembu Ndara Mane; M. Lele Maya; N. Wee Patando; O. Wee Paboba (BPS 2024)

We used the cluster random sampling technique to select the sub-districts and villages in the agro-ecosystem zones. Respondents were selected based on their residential villages (or *Kampung* in the local dialect), where multiple families reside, engage in work, and establish their settlements. Village chiefs and community leaders coordinated the selection process. All selected respondents were involved in livestock farming and *Kaliwo* agroforestry during the study period. The research procedure has been consulted to the Research Ethic Committee fulfilled the research ethic guidelines set by Universitas Jenderal Soedirman.

Instruments and respondents

This study applied the qualitative descriptive method, collecting data through survey questionnaires, interviews, Focus Group Discussions (FGD), and direct observation of 420 traditional farmers from three agro-ecosystem zones. The primary data included the activities of the farmers, the types of livestock they raised, and the sources of their forage. For the secondary data, we sourced information about the villages involved in this study from the Statistics Office and Associated Agencies (BPS 2024). In November 2022, we validated the open-ended questionnaire in Kalembu Weri Village involving 45 farmers. The interviews initially targeted 800 farmers (50 farmers in each village). Upon the interview's completion, we gathered 420 valid respondents (see Table 1).

Structured interviews

We conducted structured interviews to gather information, taking into account the following factors: (i) A subset of respondents communicated predominantly in indigenous languages: Kodi, Wewewa, and Loura. We selected enumerators based on their geographical origin and proficiency in their local dialects. (ii) During the field validation of the interview instrument in Kalembu Weri Village, we observed that several respondents, educated to senior high school and university levels, struggled to independently respond to the posed questions, requiring multiple clarifications from us. This observation prompted significant efforts to enhance the tool and instruct enumerators on a guided interview method, which utilized a framework to facilitate comprehensive response recording during the interview. (iii) We gave enumerators training and debriefing on interview techniques, from opening to closing the interview. Additionally, they received training on filling out interview answer sheets. The number of enumerators in each village was 10-12 people, and each enumerator interviewed five respondents. We conducted the interviews between January 29, 2023, and February 17, 2023.

Participant observation

We conducted participatory observation, a passive form of observation, from November 2022 to May 2023, assuming the role of mere external observers of activities to gain a deeper understanding of the social context and situation of the respondents. This method offers a comprehensive perspective and direct experience, enabling an inductive approach that remains uninfluenced by prior concepts or views, thereby facilitating the possibility of making discoveries. In this study, we positioned ourselves to identify elements that enumerators might overlook due to unarticulated or perceived insignificant information during interviews. Another benefit of participatory observation is identifying phenomena that transcend the respondent's immediate awareness, capturing personal impressions and experiencing the ambiance of the respondent's social environment. Our background in the Wewewa and Loura areas, immersed in livestock and agricultural practices, is another salient consideration.

Focus Group Discussion (FGD)

We conducted the first FGDs at the homes of farmers or village heads, community leaders, and religious leaders in the Loura area (Karuni and Ramadana), Wewawa area (Kalembu Weri, Malimada, Kalembu Ndara Mane), and Kodi region (Tanjung Karoso, Kori, and Tana Mete). The FGDs employed an interview guideline to delve deeper into each village's agricultural and livestock systems. We conducted the second FGDs at Unika Weetebula Campus, with participation from the head and staff of the Livestock and Animal Health Service Office of Southwest Sumba District, 14 village heads from three sample areas, and five community and customary leaders.

Data analysis

We validated data from interviews, observations, and focus group discussions using the triangulation method and then conducted descriptive analysis using statistical and non-statistical methods. A statistical analysis was conducted to examine the relationships and associations among the variables, including cross-tabulation and chi-squared analysis, using SPSS Statistics v25 (IBM, NY USA). We grouped the processed data based on variables and respondents, tabulated, presented, and calculated the results to address the formulation of the problem.

Table 1. Respondent distribution across villages in three agro-ecosystem zones in Southwest Sumba District, Indonesia

Agro-ecosystem zone	Sub-districts	Villages	Number of respondents
Loura	Loura	Karuni	23
		Rama Dana	22
		Wee Pangali	5
Sub total			50
Kodi	Kodi	Tanjung Karoso	39
	Kodi Bangedo	Rada Loko	50
		Tana Mete	14
	Kodi Balaghar	Panenggo Ede	39
	Kodi Utara	Kori	20
		Bukambero	19
Sub total			181
Wewewa	Wewewa Barat	Kalembu Kanaika	45
		Kalembu Weri	45
	Wewewa Timur	Kalembu Ndara Mane	22
		Lele Maya	22
	Wewewa Tengah	Wee Patando	30
	Wewewa Utara	Wee Paboba	25
Sub total			189
Total			420

RESULTS AND DISCUSSION

Respondent characteristics

The farmers in our study were 47 years old on average, and 56% lacked formal education or failed to complete elementary school. Most farmers engaged in traditional husbandry, a practice passed down from earlier generations that employed younger and older farmers. Despite reaching a productive age, farmers' productivity remained suboptimal, primarily due to a lack of educational background that could have enhanced their capabilities. In Southwest Sumba, a farmer's family typically consisted of 6-7 individuals, with 2-3 family members managing *Kaliwo* agroforestry, small farmland (*kebun*), paddy fields, and livestock. Approximately 2-3 family members pursued formal education. Family labour availability is a significant asset in the continuity of traditional animal husbandry while ensuring operational effectiveness and efficiency. However, the significant number of dependents the family supports for education may lower overall income levels and, as a result, limit opportunities for farming business expansion (Leslie et al. 2015; Duffy et al. 2021).

Sodiq et al. (2017) reported that educational attainment significantly influences farmers' capacity to absorb innovations and technological advancements. Individuals within the productive age range exhibited a greater propensity for the assimilation of novel innovations, attributable to their relatively sound cognitive abilities and emotional stability, which facilitate the acceptance of guidance and innovative practices. We anticipate a positive correlation between an increase in educational levels and the adoption of technology to improve agricultural practices. Factors pertaining to education, knowledge, and experiential learning acquired through entrepreneurial activities represent critical internal determinants influencing an individual's motivation to pursue development and maximize profitability. The demographic characteristics of ageing and low educational attainment among farmers within a given region constitute a fundamental attribute of traditional agricultural and livestock production.

Farmers' ownership and comprehension of *Kaliwo* agroforestry

Approximately 79% of farmers (n = 333) owned *Kaliwo* agroforestry and had different understandings of the *Kaliwo* system, as highlighted in Table 2. Table 2 shows that 53.5% of the respondents (n = 178) resided in the Wewewa area and practiced *Kaliwo* to cultivate perennial plants, which include coffee, candlenut, cocoa, cashew, bamboo, areca nut, coconut, mahogany, and teak, and a diverse array of other plantation and forestry species. The rest 46.5%, particularly in Kodi and Loura areas, regarded *Kaliwo* as a living kitchen or small garden behind or around the house used to grow vegetables, chilli, tomatoes, ginger, galangal, turmeric, papaya, bananas, and various other types of seasonal crops. Therefore, *Kaliwo* can be regarded as a piece of land to grow various plantation crops, food crops, forest plants, and traditional medicinal plants around the farmer's premises, separated from a small farmland usually planted with food crops such as corn, rice and cassava. Furthermore, *Kaliwo*, also known as *Kaliwu* in some other Sumba dialects, constitutes an expanse of open land designated for the planting food crops on level terrain and low-lying terrain and plantation and forestry crops on elevated topography (Njurumana et al. 2021; Hartoyo et al. 2022). It is essential to understand farmers' comprehension of the concept and practice of *Kaliwo* because it significantly influences their behaviour in *Kaliwo* management and resource allocation.

Land area in *Kaliwo* agroforestry

Sumba farmers' *Kaliwo* perspectives distinguish small farmland from rice fields; the small farmland typically hosts tubers, corn, rice, and seasonal agricultural crops, while the latter solely cultivate rice, whether irrigated or not. Table 3 indicates that 47% of farmers owned *Kaliwo* (1,000 to 5,000 m^2), and 42% have small farmland from 5,000 to 10,000 m^2. The land size can increase if a farmer acquires additional marginal land to convert into *Kaliwo*. However, the size of *Kaliwo* can also decrease due to the distribution of inheritance to children or sale by the owner. Based on the observations and FGDs, the size of *Kaliwo* tends to increase with the price of plantation and forestry commodities, while the price of corn and rice did not increase substantially.

In the Wewewa area, farmers converted perceived less arable land into *Kaliwo* agroforestry, prioritizing more fertile land for cultivating seasonal crops like maize and rice. On the other hand, the Loura and Kodi areas experienced a decline in the allocated *Kaliwo* area as a result of the conversion of *Kaliwo* agroforestry land into residential developments and the farmers' tendency to sell or mortgage their *Kaliwo* land and gardens to fund education and traditional ceremonies (Njurumana et al. 2021; Setianto et al. 2024). Additionally, land transactions with tourism investors have significantly increased, especially as Sumba Island has gained recognition as a destination for nature tourism over the past decade.

Types of cultivated crops in *Kaliwo* agroforestry

Southwest Sumba applies the *Kaliwo* agroforestry cropping pattern over two physiographic zones: lowlands (0-400 masl) and highlands (300-800 masl), each exhibiting a unique cropping scheme. We identified three distinct cropping configurations, with each primary crop constituting 50-70% of the cropping scheme. Cropping pattern I was in the Loura area, where the most common commodity was cashews, followed by supplementary crops such as agricultural species, plantation varieties, and fodder forage. Cropping pattern II was used in the Kodi area, where coconut and cashew were the main crops and other crops were grown to supplement them, as shown in Table 4. We observed Cropping pattern III in the elevated terrains of the Wewewa area, which featured primary crops like coffee, coconut, and areca nut, as well as supplementary crops like agricultural species, forestry cultivars, and fodder forage.

The cultivation period for *Kaliwo* agroforestry systems spans from 20 to 40 years, matching the economic lifespan of three primary commodities: coffee, coconut, and cashew trees. Wewewa's *Kaliwo* agroforestry boasts a wider variety of plantation and forestry crops than Kodi and Loura, primarily due to its extensive coffee, candlenut, areca nut, durian, and rambutan cultivation. The temperate physiographic conditions at an altitude of approximately 800 masl significantly benefit farmers who cultivate coffee as the primary crop. Coffee plants are absent from cropping pattern I, as they thrive optimally at elevations exceeding 750 masl (Duffy et al. 2021). Cashew represents the primary crop in the lowland regions of Kodi and Loura.

The crops in Figure 2 may not contribute economic benefits equally to farmers. In fact, species like *gamal* (*Gliricidia sepium* (Jacq.) Kunth), *lamtoro* (*Leucaena leucocephala* (Lam.) de Wit), calliandra (*Calliandra calothyrsus* Meisn.), the banten tree or *kesi*, and moringa (*Moringa oleifera* Lam.) failed to generate an economic return. As a result, farmers choose to cultivate coffee, coconut, and cashew as primary crops because they can yield annual harvests and have longer production periods compared to alternative crops, especially woody species that require lengthy maturation periods and infrequent harvests (Parikesit et al. 2021).

Plant diversity in *Kaliwo* is important in supporting business diversification, the community's economy, and preserving socio-cultural values through its continued function as a cultural attribute (Datta et al. 2024). The diversity of plant species cultivated in *Kaliwo* creates a natural agro-ecosystem and ecological value through preservation (Rozaki et al. 2021). Farmers in Southwest Sumba stated that the multivarious plants cultivated in *Kaliwo* have elevated the community's social status. Interdependence among farmers, cultural values, and agricultural and livestock farming would successfully develop sustainable agricultural and livestock production systems in Southwest Sumba.

Livestock population

Table 5 presents the livestock ownership among farmers in three areas, revealing that smallholders in the Kodi and Wewewa areas have fewer than five livestock. In contrast, the Loura area has more than five livestock. The restricted quantity of livestock maintained was predominantly attributable to insufficient capital to start a livestock enterprise, high mortality rates from diseases of the animals, unavailability of feed (Golla 2021), and inadequate knowledge and skills of effective livestock management practices (Duguma and Janssens 2021; Sánchez-Romero et al. 2021). The extensive utilization of productive animals, primarily for economic, educational, and cultural purposes, also influences limited livestock ownership (Setianto et al. 2024).

Livestock reproductive capability is important in controlling its population size. In general, the fecundity rate is low in buffalo (46%), cattle (53%), and horses (46%). In contrast, the mortality rate is low in ruminant animals such as buffalo (1%), cattle (4.6%), and goats (6.2%), but high in non-ruminant animals like horses (13.7%) and pigs (28.7%). The litter size for goats (1.3) and pigs (4-6) is suboptimal, comparable to the average litter size of 4-6 per birthing event in Kupang (Wea 2009; Wily et al. 2022). The ideal litter size for pigs is 10 piglets per farrowing.

Factors influencing livestock productivity are maternal age, breed, milk production, and the quality of sires for breeding (Wea et al. 2020; Ndona et al. 2024). The lowest mortality rate of livestock was observed in the Wewewa area. Furthermore, the characteristics of the farmers, such as their age, education, farming experience, number of family dependents, and motivation, along with their understanding of breeding, feeding, reproduction, and health, contribute to the productivity of livestock (Gunawan et al. 2019; Sekaran et al. 2021).

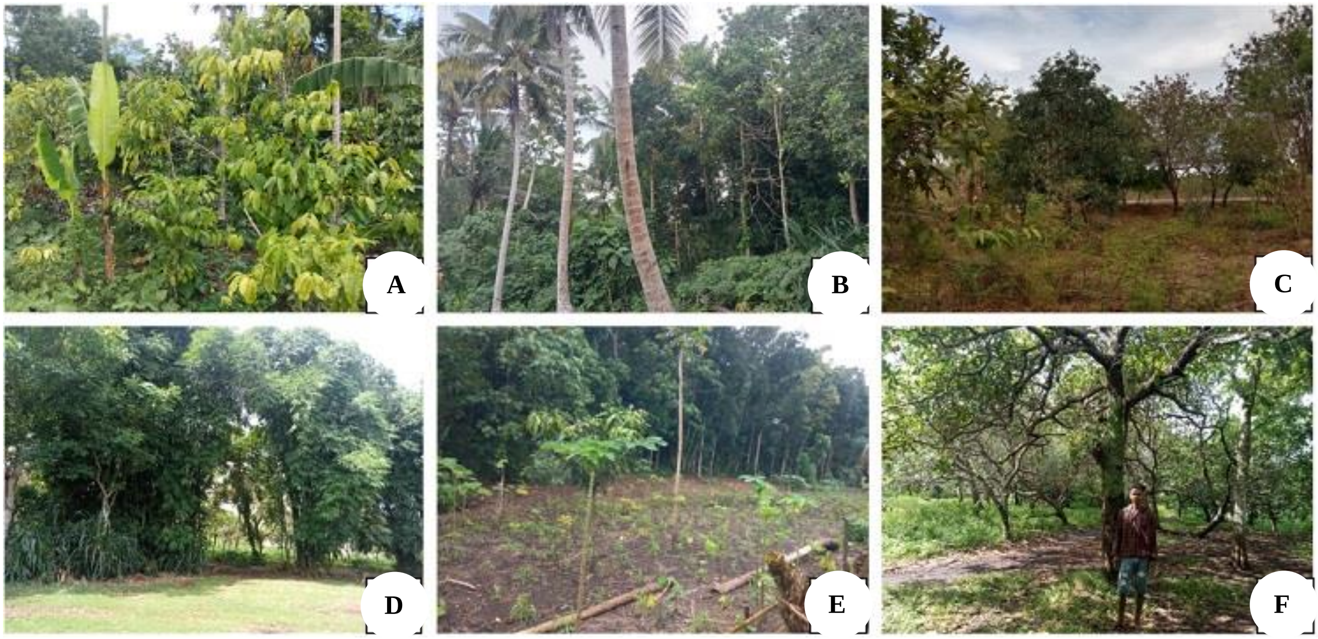

Figure 2. *Kaliwo* agroforestry in Southwest Sumba District, Indonesia: A, E: Wewewa; B, D, F: Kodi; and C. Loura

Table 2. Utilization and characteristics of the *Kaliwo* agroforestry in Southwest Sumba District, Indonesia

Utilization and characteristics	Plant species	Number of respondents	Percentage
Kodi area			
It is a site for cultivating perennial plants and other plantation and forestry plants.	Cashew (*Anacardium occidentale*), guava (*Psidium guajava*), coffee (*Coffea arabica*), coconut (*Cocos nucifera*), areca nut (*Areca cathecu*), jackfruit (*Artocarpus communis*), mango (*Mangifera indica*), orange (*Citrus* sp.), soursop (*Annona muricata*), avocado (*Persea americana*), mahogany (*Swietenia machrophylla*), white teak (*Gmelina arborea*), local teak (*Tectona grandis*), bamboo (*Bambusa* sp.)	42	33.1
It is for cultivating perennial plants and seasonal crops.	Cashew (*Anacardium occidentale*), guava (*Psidium guajava*), coffee (*Coffea arabica*), coconut (*Cocos nucifera*), areca nut (*Areca cathecu*), jackfruit (*Artocarpus communis*), mango (*Mangifera indica*), orange (*Citrus* sp.), soursop (*Annona muricata*), avocado (*Persea americana*), mahogany (*Swietenia machrophylla*), white teak (*Gmelina arborea*), local teak (*Tectona grandis*), bamboo (*Bambusa* sp.), taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chili (*Capsicum annum*), tomato (*Solanum lycopersicum*)	4	3.1
It serves as a living kitchen garden where vegetables are cultivated	Banana (*Musa* sp.), pineapple (*Ananas comosus*), papaya (*Carica papaya*), taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chili (*Capsicum annum*), tomato (*Solanum lycopersicum*)	51	40.2
It is a small garden near or behind the house that should receive regular maintenance	taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chili (*Capsicum annum*), tomato (*Solanum lycopersicum*)	30	23.6
Wewewa area			
It is a site for the cultivation of perennial plants and various other types of plantation and forestry plants	Coffee (*Coffea arabica*), coconut (*Cocos nucifera*), areca nut (*Areca cathecu*), avocado (*Persea americana*), mondong (*Spondias dulcis* Parkinson), candlenut (*Aleurites moluccanus*), rambutan (*Nephelium lappaceum*), durian (*Durio zibethinus*), sapodilla (*Manilkara zapota*), jackfruit (*Artocarpus communis*) cacao (*Theobrom cacao*), cashew (*Anacardium occidentale*), mango (*Mangifera indica*), orange (*Citrus* sp.), soursop (*Annona muricata*), avocado (*Persea americana*) mahogany (*Swietenia machrophylla*), white Teak (*Gmelina arborea*), local teak (*Tectona grandis*), bamboo (*Bambusa* sp.)	120	74.1
It is characterized as a living kitchen wherein vegetables and various other short-lived plants are grown	Banana (*Musa* sp.), pineapple (*Ananas comosus*), papaya (*Carica papaya*), taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chilli (*Capsicum annum*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), onion (*Allium cepa*), tomato (*Solanum lycopersicum*), siam pumpkin (*Sechium edule*), turmeric (*Curcuma longa*), galangal (*Alpinia galanga*)	26	16.0
It is a small garden near or behind the house to grow vegetables for the family's own needs	Banana (*Musa* sp.), pineapple (*Ananas comosus*), papaya (*Carica papaya*), taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chilli (*Capsicum annum*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), onion (*Allium cepa*), tomato (*Solanum lycopersicum*), siam pumpkin (*Sechium edule*), turmeric (*Curcuma longa*), galangal (*Alpinia galanga*)	16	9.9
Loura area			
It is a site for the cultivation of perennial plants.	Cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), jackfruit (*Artocarpus communis*), mango (*Mangifera indica*), avocado (*Persea americana*), orange (*Citrus* sp.), annona (*Annona squamosa*), soursop (*Annona muricata*), breadfruit (*Artocarpus communis*), guava (*Psidium guajava*), mahogany (*Swietenia machrophylla*), white teak (*Gmelina arborea*), local teak (*Tectona grandis*), and bamboo (*Bambusa* sp.)	12	27,8
It is characterized as a living kitchen wherein vegetables and short-lived crops are grown	Banana (*Musa* sp.), papaya (*Carica papaya*), chili (*Capsicum annum*), tomato (*Solanum lycopersicum*), wax gourd (*Benincasa hispida*), (*Cucurbita moschata*)	32	72.2

Table 3. The land area of *Kaliwo* agroforestry and small farmland owned by farmers in Southwest Sumba District, Indonesia

Land area (m^2)	Agro-ecosystem zone							
	Kodi (Respondent)	**%**	**Wewewa (Respondent)**	**%**	**Loura (Respondent)**	**%**	**Total (Respondent)**	**%**
Kaliwo								
1. <1,000	46	49	19	14	11	38	76	30
2. 1,000-5,000	31	33	76	58	14	48	121	47
3. 5,001-10,000	13	14	25	19	0	0	38	15
4. >10,000	4	4	12	9	4	14	20	8
Total	94		132		29		255	
Small farmland								
1. <1,000	10	7.7	8	5.8	13	36.1	31	10.2
2. 1,000-5,000	51	39.2	49	35.5	12	33.3	112	36.8
3. 5,001-10,000	55	42.3	65	47.1	8	22.2	128	42.1
4. >10,000	14	10.8	16	11.6	3	8.3	33	10.9
Total	130		138		36		304	

Table 4. Categories of plants cultivated within *Kaliwo* agroforestry in Southwest Sumba District, Indonesia

Components	Plant species		
	Kodi	**Wewewa**	**Loura**
Plantation crops	Cashew (*Anacardium occidentale*), guava (*Psidium guajava*), coffee (*Coffea arabica*), coconut (*Cocos nucifera*), areca nut (*Areca cathecu*), jackfruit (*Artocarpus communis*), mango (*Mangifera indica*), orange (*citrus*), soursop (*Annona muricata*), avocado (*Persea americana*)	Coffee (*Coffea arabica*), coconut (*Cocos nucifera*), areca nut (*Areca cathecu*), avocado (*Persea americana*), *mondong* (*Spondias dulcis*), candlenut (*Aleurites moluccana*), rambutan (*Nephelium lappaceum*), durian (*Durio zibethinus*), sapodilla (*Manilkara zapota*), jackfruit (*Artocarpus communis*) cacao (*Theobrom, cacao*), cashew (*Anacardium occidentale*), mango (*Mangifera indica*), orange (*citrus*), soursop (*Annona muricata*), avocado (*Persea americana*)	Cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), jackfruit (*Artocarpus communis*), mango (*Mangifera indica*), avocado (*Persea americana*), orange (*Citrus* sp.), anona (*Annona squamosa*), soursop (*Annona muricata*), breadfruit (*Artocarpus communis*), guava (*Psidium guajava*)
Agricultural crops	Banana (*Musa* sp.), pineapple (*Ananas comosus*), papaya (*Carica papaya*), taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chili (*Capsicum annum*), tomato (*Solanum lycopersicum*), moringa (*Moringa oleifera*)	Banana (*Musa* sp.), pineapple (*Ananas comosus*), papaya (*Carica papaya*), taro yam (*Colocasia esculenta*), sweet potato (*Manihot utilissima*), chili (*Capsicum annum*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), onion (*Allium cepa*), tomato (*Solanum lycopersicum*), siam pumpkin (*Sechium edule*), turmeric (*Curcuma longa*), galangal (*Alpinia galanga*), moringa (*Moringa oleifera*)	Banana (*Musa* sp.), papaya (*Carica papaya*), chili (*Capsicum annum*), tomato (*Solanum lycopersicum*), wax gourd (*Benincasa hispida),* moringa (*Moringa oleifera*)
Forestry crops	Mahogany (*Swietenia machrophylla),* white teak (*Gmelina arborea*), local teak (*Tectona grandis*), bamboo (*Bambusa* sp.)	Mahogany (*Swietenia machrophylla*, white teak (*Gmelina arborea*), local teak (*Tectona grandis*), and bamboo (*Bambusa* sp.)	Mahogany (*Swietenia machrophylla),* white teak (*Gmelina arborea*), local teak (*Tectona grandis*), and bamboo (*Bambusa* sp.)
Livestock forage feed	Gamal (*Glirisidia sepium*), *lamtoro* (*Leucaena leucocephala*), calliandra (*Calliandra calothyrsus*), white teak (*Gmelina arborea*)	Kinggrass (*Pennisetum purpureum*), gamal (*Glirisidia sepium*) *lamtoro* (*Leucaena leucocephala*), calliandra (*Calliandra calothyrsus*), white teak (*Gmelina arborea*), jackfruit leaves (*Artocarpus communis*)	Gamal (*Glirisidia sepium*), *lamtoro* (*Leucaena leucocephala*), white teak (*Gmelina arborea*), and jackfruit leaves (*Artocarpus communis*)

Table 5. Types and population of livestock owned by farmers in Southwest Sumba District, Indonesia

Livestock	Kodi			Wewewa			Loura			Total
	Male	**Female**	**Sub Total**	**Male**	**Female**	**Sub Total**	**Male**	**Female**	**Sub Total**	
Ongole cattle	2	6	8	1	4	5	10	33	43	56
Buffalo	22	22	44	33	23	56	8	7	25	125
Horse	19	11	30	4	4	8	5	12	17	55
Goat	54	75	129	55	82	137	50	107	157	423
Pig	68	81	149	165	223	388	45	70	117	654
Domestic chicken	998	483	1481	746	334	1080	535	223	758	3319
Domestic duck	56	24	80	85	59	144	153	64	217	441

Forages as feed from *Kaliwo* agroforestry

Kaliwo is a significant source of forage for various categories of animals (see Table 6). Buffaloes, cattle, horses, and goats in the Wewewa and Kodi areas are tethered near the *Kaliwo*, which provides them with chopped banana stems and leaves, *lamtoro* leaves, jackfruit leaves, white teak leaves, and a variety of grasses. Pigs were fed on forages such as taro leaves, stems, and papaya leaves. During the rainy season, farmers in Loura cultivated various crops from *Kaliwo's* small farmland, including *Corchorus olitorius* L. (local name: *ropu marapu*), *Commelina benghalensis* L. (local name: *kangauka moro*), *Boerhavia diffusa* L. (local name: *kangauka rara*), *Digera muricata* (L.) Mart. (local name: *raghi*), *Celosia argentea* L. (local name: *kapodukota*), and *Euphorbia heterophylla* L. (local name: *kapokoka*) (Figure 3). While *Kaliwo* crops had substantially contributed to the overall availability of animal feed in Sumba, they did not entirely fulfil the nutritional requirements of livestock (Njurumana et al. 2021). Simultaneously, farmers in Loura not only confine their animals or allow them to graze in the *Kaliwo* and domestic yards but also utilize the mini ranch (800 ha) owned by the community for the free grazing of cattle, buffaloes, horses, and goats.

Table 6. Types of forages derived from *Kaliwo* that were utilized as feed for various types of livestock in Southwest Sumba District, Indonesia

Types of forage	Types of livestock
Lamtoro (*Leucaena leucocephala*)	Buffalo, goat, and pig
Kaliandra *(Calliandra calothyrsus*)	Buffalo, goat, and pig
Gamal (*Glirisidia sepium*)	Buffalo, goat, and pig
King grass (*Pennisetum purpuphoides*)	Buffalo, goat, horses, and pig
Elephant grass (*Pennisetum purpureum*)	Buffalo, cattle, goats, and horses
White teak (*Gmelina arborea*)	Goats
Jackfruit leaves (*Artocarpus communis*)	Goats
Banana leaves and stems (*Musa paradisiaca*)	Buffalo, cattle, goats, horses, pig, chicken, and ducks
Caladium leaves, stems, and tubers (*Caladium esculentum*)	Pig, chicken, and ducks
Sweet potato (*Ipomoea batatas*)	Goats, pig, chicken, and duck
Papaya leaves and fruit (*Carica papaya*)	Goats, pig, chicken, and duck
Cassava leaves and tubers (*Manihot esculenta*)	Goats, pig, chicken, and duck
Chayote fruit (*Sechium edule*)	Pig, chicken, and duck
Daun pohon kesi/banten (*Lannea coromandelica*)	Goats
Moringa leaves (*Moringa oleifera*)	Pig, chicken, and duck
Kersen leaves and fruit (*Muntingia calabura*)	Goats, pig, chicken, and duck
Imperata grass (*Imperata cylindrica*)	Buffalo, cattle, goats, and horses
Various grasses *(Brachiaria decumbens*, *Cynodon dactylon*, *Cyperus rotundus*, *Eleusine Indica Heteropogon insignis*, *Panicum maximum*)	Buffalo, cattle, goats, and horses

Figure 3. Livestock feed from the small farmland and *Kaliwo* in Loura area of Southwest Sumba District, Indonesia: A. *Corchorus olitorius* (local name: ropu marapu); B. *Commelina benghalensis* (local name: kangauka moro); C. *Boerhavia diffusa* (local name: *kangauka rara*); D. *Digera muricata* (local name: raghi); E. *Celosia argentea* (local name:kapodukota); F. *Euphorbia heterophylla* (*local name:* kapokoka)

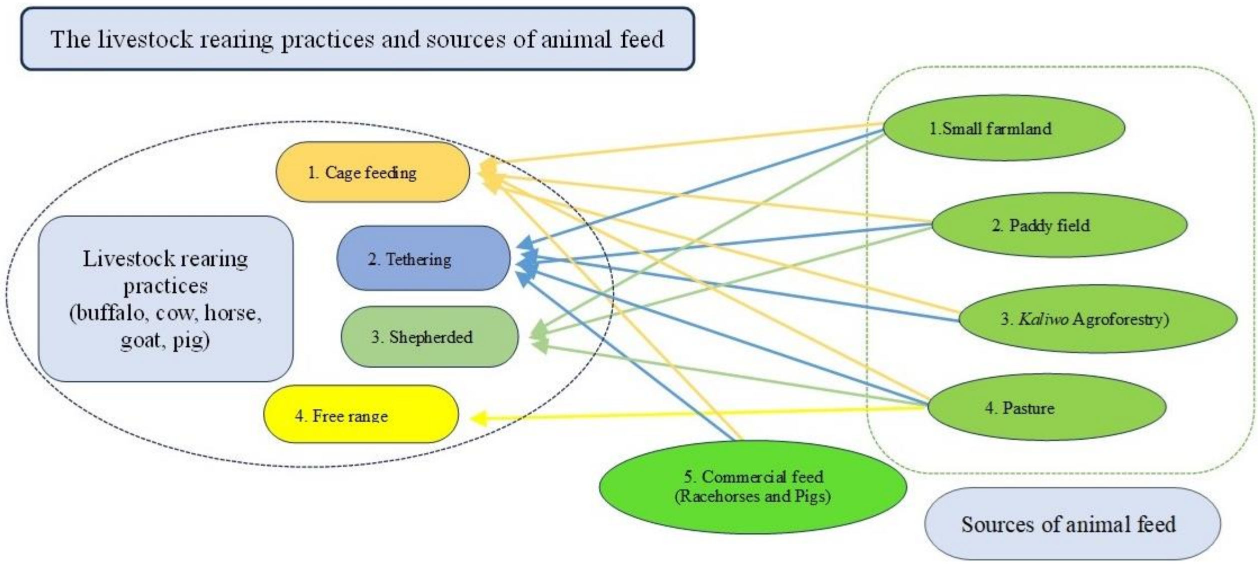

Figure 4. The livestock rearing practices and sources of animal feed in Southwest Sumba District, Indonesia

Farmers in Sumba typically leave agricultural by-products like rice husks, corn stalks, and corn leaves to decompose in the fields, as they rarely use these materials for animal feed. Farmers in the Loura area observed a unique forage feeding practice. They are accustomed to burning the rainfed fields, paddy fields, and fresh forage and grass to prepare the land for the new planting season. Due to their small cattle population, farmers lack familiarity with feed conservation and feed fermentation techniques, such as silage and hay, which can enhance the shelf life and nutritional quality of fresh forage. All cattle, except racehorses and pigs, did not receive nutritional supplements, concentrated feed, rice bran, or pollard. Despite this, the pigs received minimal concentrated feed to enhance their palatability. The monthly cost of feeding, which included taro stalks, rice bran, and pollard, varied between IDR 100,000 and IDR 300,000 (1 US$ = IDR 15,500), depending on the number of livestock on the farm and was relatively expensive for farmers in Sumba Island.

Figure 4 shows that the accessibility of feed derived from the nearest sources significantly influences the livestock rearing practices employed in Southwest Sumba. During the dormant session, farmers allowed buffalo, cattle, horses, and goats to graze in indigenous forests, grasslands, rice fields, agricultural fields, unplanted areas around *Kaliwo*, or any other location where grass grew. The cattle grazed during the day for 8 to 10 hours (07:00±17:00) and were confined at night or tethered near the residence. Farmers made the drinking water available after the cattle grazed or foraged in the field. Farmers in the Loura area and, to a lesser extent, Kodi, are accustomed to releasing their livestock into fields or mini ranches to source their feed and water independently. The proprietors typically inspected the livestock at monthly intervals. They occasionally repaired the fencing of the mini ranches during the planting season at the onset of the rainy season to prevent the livestock from encroaching on the cultivated small farmland.

Farmers in Sumba faced difficulty providing a stable supply of forage or feed during the dry season. During this season, livestock owners burned pastures in Loura to encourage new grass growth for ruminants (Watuwaya et al. 2022) and frequently converted grazing lands in Kodi and Wewewa into agricultural fields and *Kaliwo*. Meanwhile, the limited supply of rice bran and pollard during the dry season posed a specific challenge for swine and poultry farmers in Southwest Sumba, increasing their prices. Demand for maize stalks increased from the end of the dry season through the rainy season due to competition between livestock and humans for maize, the staple food in Sumba. For instance, during the monsoon months of January and February, the price of dry-peeled maize increased from IDR 3,000-5,000/kg to IDR 10,000/kg.

Free-range chickens, ducks, goats and pigs in *Kaliwo*

Farmers in Southwest Sumba have implemented the *Kaliwo* agroforestry system, which provides an ideal environment for extensively rearing chickens and ducks. Farmers let chickens and ducks forage in the *Kaliwo* ecosystem in the morning, then confine them to the household yard to feed on corn. As evening approaches, chickens habitually roost on arboreal structures within the *Kaliwo* adjacent to the dwelling. Despite the economic benefits of free-range husbandry, predators such as eagles, serpents, and canines, as well as monitor lizards, prey on many chickens and ducks. Furthermore, respondents indicate that the susceptibility of chickens and ducks to various diseases is a significant concern, with the mortality rate due to illness particularly exacerbated during transitional seasonal periods. In the Loura area, farmers allowed pigs and goats to graze independently within the *Kaliwo* area and the adjacent agricultural plots, especially during the post-harvest of crops like maize, legumes, and cucurbits. Farmers would return the pigs and goats to their enclosures in the afternoon and provide them with water in the pen. Farmers primarily fed chickens and ducks with maize, rice, vegetable trimmings, and fruit scraps, but some also purchased commercial feed concentrates from agricultural supply stores (Figure 5). The expenditure on supplementary feed for chickens and ducks varied significantly, ranging from IDR 15,000 to IDR 100,000 monthly, contingent upon the quantity of livestock maintained. Reports suggest that free-range and organic systems promote animal welfare-friendly production systems, assist traditional farmers in cutting production costs, and promote sustainable farming that benefits crops and livestock (Adam et al. 2021). On the other hand, free-range and organic systems could put food safety and human health at risk by introducing parasites, avian flu, campylobacteriosis, salmonellosis, and drug residues (Kijlstra et al. 2009).

Housing and *Kaliwo*

Southwest Sumba categorizes livestock enclosures into natural enclosures, which feature open living conditions, and manual enclosures. Natural enclosures house cattle in open spaces, secure them to wooden posts, and allow them to rest in either the yard or the adjacent house yard. Manual enclosures refer to fortified structures constructed from rudimentary materials designed to provide shelter for livestock. The principal aim of these enclosures is to mitigate production expenses (Taek et al. 2021). Often located beneath traditional stilt houses or in separate areas surrounding the homestead, these livestock pens, fabricated from indigenous materials (Figure 6), serve their intended purpose. However, traditional livestock husbandry practices frequently neglect the comfort of livestock and protective functions against various threats.

Figure 5. Free-range livestock in *Kaliwo* and around houses of farmers in Southwest Sumba District, Indonesia

Figure 6. Manual livestock pens made from local materials sourced from *Kaliwo* in Southwest Sumba District, Indonesia

Figure 6 shows how livestock enclosures were built to house buffalo, cows, horses, goats, and pigs. These enclosures were made from bamboo, *gamal* (*G. sepium*), *lamtoro* (*L. leucocephala*), and other plants that grow naturally in *Kaliwo*. Some farmers repurpose the bark of *waru* trees, the outer layers of young bamboo stalks, and the leaves from coconut branches as binding materials for the pens, while others use nails for the same purpose. Roofless pens are for buffalo and cattle, while roofed pens made of thatch, bamboo, or repurposed tins were for horses, goats, and pigs. Traditionally, woven coconut leaves served as nesting boxes for brooding chickens.

Livestock production system based on crop-livestock-agroforestry *Kaliwo* systems

The Integrated Crop-Livestock-Agroforestry *Kaliwo* Systems (ICLFS) is an integrated agriculture, livestock production, and agroforestry *Kaliwo* system. The *Kaliwo* agroforestry system plays a pivotal role in supplying forage feed resources to livestock, providing locations for livestock rearing, and facilitating the procurement of materials necessary for livestock housing in the region of Southwest Sumba. ICLFS has been employed by farmers who leverage various local resources, including *Kaliwo* agroforestry, cultivated small farmland, paddy fields, and grazing lands adjacent to gardens and forests. This study revealed numerous benefits of this combined approach, including using various animal feed types derived from *Kaliwo*, using agricultural waste for animal feeding, and applying animal waste as fertilizer in both *Kaliwo* and garden areas. Additionally, farmers utilized livestock manure to enhance the fertility of horticultural crops, including tomatoes, chillies, and beans. In particular, some farmers in the Wewewa region with proximity to *Kaliwo* agroforestry and their livestock employ a practice during the rainy season wherein they construct ditches to channel livestock manure from the livestock pens to the surrounding *Kaliwo* agroforestry.

This integrative system can sustain the carrying capacity and ecological diversity within the environment as a viable alternative for sustainable agricultural livestock practices (Ndona et al. 2024). The operational methodology adheres to Low External Input Sustainable Agriculture (LEISA) principles or adopts a zero-cost approach, thereby facilitating the production of 4F products (Food, Feed, Fertilizer, and Fuel). *Kaliwo* agroforestry plays an important role in supporting the community's ecological, economic, and social aspects. The practice of complex agroforestry in rural areas has sustained human livelihoods over generations, as this land utilization framework can yield food, shelter, energy, fodder, and medicinal resources. These traditional forms and agroforestry practices exhibit a harmonious relationship with the environment, enabling their sustainability (Bayala and Prieto 2020; van Noordwijk 2021).

In conclusion, farmers in Southwest Sumba rely on *Kaliwo* as a significant source of revenue from cultivating perennial and seasonal crops. Ruminants (goats, buffaloes, and cattle) and non-ruminants (pigs and horses) rely on *Kaliwo* as a source of forage, especially during the dry season when grazing lands severely restrict forage availability. Additionally, *Kaliwo* provides a free-range rearing environment for poultry, including chickens and ducks, and a source of local materials for constructing livestock enclosures in Loura. The study's findings are a foundation for developing strategies to improve livestock production utilizing the *Kaliwo* agroforestry system. Beyond its role as an economic resource through harvesting agricultural, forestry, and livestock products, *Kaliwo* agroforestry exemplifies a sustainable integration system for agriculture and livestock, particularly in light of the rapidly occurring climate change observed in recent decades. The study's findings reveal that traditional *Kaliwo* agroforestry demonstrates the community's proficiency in managing diverse resources efficiently, effectively, and sustainably. Farmers engage in managing agricultural, plantation, and livestock activities in a systematic, interconnected, and mutually reinforcing manner. Further studies are advised to determine the development strategy of *Kaliwo* agroforestry, particularly its role in the livestock production system in Southwest Sumba.

ACKNOWLEDGEMENTS

This research was financially supported by the Directorate of Research Technology and Community Services, the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia, through Fundamental Research Grant of the Universitas Jenderal Soedirman, Contract Number 20.28/UN23.35.5/PT.01.00/VI/2024, Yayasan Pendidikan Nusa Cendana (Yapnusda) and MISEREOR Germany. The author would like to thank the enumerator, the local community, and the elders of the Loura, Wewewa, and Kodi communities in Southwest Sumba District, Indonesia, for contributing and sharing their expertise and experience with us. The research complies with the applicable research ethics guidance of Universitas Jenderal Soedirman.

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