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AGROECOSYSTEM-BASED LIVESTOCK AND SUSTAINABLE FEED SYSTEMS

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PREFACE

This volume brings together a collection of scholarly contributions that examine contemporary challenges and innovations in sustainable agriculture and livestock production. In the face of increasing pressures from climate change, resource scarcity, and rising global demand for food, the development of efficient and resilient agroecosystems has become a central concern for both researchers and practitioners.

The chapters in this book address key themes related to agroecosystem-based livestock systems and sustainable feed solutions. The exploration of pasture management in tropical drylands highlights the importance of balancing climatic, ecological, and management factors to maintain productivity and prevent land degradation. In addition, the discussion on the valorization of organic kitchen waste as poultry feed reflects emerging approaches within the circular bioeconomy, demonstrating how waste materials can be transformed into valuable resources while reducing environmental impacts.

By adopting an interdisciplinary perspective, this volume integrates insights from agricultural sciences, animal production, environmental sustainability, and resource management. It contributes to academic discourse while also offering practical implications for farmers, researchers, and policymakers seeking to develop adaptive and sustainable food production systems.

It is hoped that this book will serve as a valuable resource for scholars and practitioners interested in agroecosystems, livestock management, and sustainable agriculture, while encouraging further research on innovative strategies that enhance productivity without compromising ecological balance.

Editorial Team
April, 2026
Türkiye

CHAPTER 1

AGROECOSYSTEM-BASED APPROACH TO THE MANAGEMENT OF TROPICAL DRYLAND PASTURES TO SUPPORT THE SUSTAINABILITY OF AGROPASTORAL AND RUMINANT PRODUCTION SYSTEMS

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INTRODUCTION

Tropical drylands represent an agroecosystem with a strategic role in the development of ruminant livestock production, particularly through the utilization of pastures. Pastures serve as the primary source of forage, supporting labor efficiency and the sustainability of extensive livestock production systems. However, the characteristics of tropical drylands—marked by limited water availability, seasonal climatic variability, and relatively low soil fertility—render pasture productivity highly vulnerable to degradation if not managed appropriately.

In Indonesia, pasture management is generally still based on natural and semi-intensive systems that are highly dependent on climatic conditions and seasonal variability. The transformation of grazing systems from extensive to more intensive patterns, when not accompanied by proper management of land carrying capacity, often leads to declines in vegetation quality, soil degradation, and reduced livestock carrying capacity. Excessive grazing intensity has been shown to decrease soil quality, organic carbon content, and the botanical composition of forage, thereby threatening the sustainability of pasture agroecosystems in tropical dryland areas.

An agroecosystem-based approach to pasture management emphasizes the importance of maintaining a balance among biophysical factors (climatic and edaphic), vegetation composition, livestock carrying capacity, and human technological interventions. Managing carrying capacity through the regulation of grazing and rest periods, diversification of plant species with a balanced proportion of grasses and legumes, and the implementation of agropastoral systems are key strategies to maintain productivity and sustainability of pastures. Furthermore, carrying capacity assessment using the Carrying Capacity Index (CCI) provides a quantitative basis for determining the safe utilization level of forage resources for grazing livestock.

The success of pasture management is determined not only by biophysical aspects but is also strongly influenced by the quality of human resources and institutional support. Farmers of productive age with relevant experience, education, and access to training and technology play a crucial role in optimizing land carrying capacity utilization.

Support from livestock service facilities, farmer institutions, and marketing systems also serves as key factors in enhancing the efficiency and sustainability of ruminant livestock production systems in tropical dryland areas.

Therefore, studies on an agroecosystem-based approach in tropical drylands are essential for formulating pasture management strategies that are grounded in land carrying capacity, ecologically sustainable, and adaptive to the socio-economic conditions of farmers, with the aim of supporting the sustainable improvement of ruminant livestock productivity.

1. PASTURE

A pasture is defined as an area where forage plants are available for livestock to graze and meet their nutritional needs within a short period. Haba Ora (2015), a pasture is an area designated for ruminant livestock grazing under extensive management to support labor efficiency in livestock farming. A pasture can also be defined as land planted with superior grasses and/or legumes (species tolerant to trampling by livestock) serving as a location for livestock grazing (Riwu Kore & Haba Ora, 2019a). Thus, a pasture refers to an area used for livestock grazing because feed resources are still available.

Forage sources from pastures for ruminants can be classified into four categories: forage from natural pastures, forage from improved permanent pastures, forage from temporary pastures, and forage from irrigated pastures (Carreira et al., 2025). These forages may consist of grasses, legumes, or mixtures of both.

Pasture management in Indonesia is generally based on land and forage carrying capacity, as follows (Ibrahim & Usman, 2021).

1. Natural grazing system. Livestock graze on natural pastures without intensive management, with the main forage source coming from natural vegetation that is highly dependent on seasonal and climatic conditions.
2. Semi-intensive grazing system. Pastures are managed to a limited extent through vegetation improvement, regulation of grazing periods, and supplementary feeding during certain seasons to maintain livestock productivity.

3. Intensive grazing system or agropastoral system. Pastures are managed intensively with the integration of forage crops and livestock, combined with land management, fertilization, carrying capacity regulation, and soil and water conservation to ensure the sustainability of production.

Meanwhile Marchegiani et al. (2025), classify pasture carrying capacity development patterns for ruminant livestock as follows:

1. Pasture-based development. Ruminant livestock are developed using natural or improved pastures as the primary forage source, with land carrying capacity managed to maintain a balance between livestock population and forage availability.
2. Crop–livestock integration-based development. Livestock systems are developed through the integration of livestock production with food crops or plantations, allowing crop residues to be used as animal feed and livestock manure as fertilizer, thereby enhancing the efficiency and sustainability of farming systems.
3. Feed intensification and diversification-based development. Livestock development focuses on improving the quality and quantity of forage through the introduction of superior forage species, the use of supplementary feed and agricultural by-products, and the application of more intensive management practices in accordance with land carrying capacity.

Alturk et al. (2022), suggest that the ecological suitability of land for livestock development can be recommended through two main patterns:

1. Spatial diversification pattern. Livestock development is carried out on land that already has a prior use, such as cropland or plantations, through an integrated or crop–livestock farming approach.
2. Spatial extensification pattern. Livestock development is conducted on underutilized potential lands, such as certain forest areas or grasslands, while still considering land carrying capacity and sustainability principles.

Declines in pasture quality can also result from the transformation of extensive systems into intensive ones, such as the use of forest land or drylands as communal grazing areas. If left unmanaged, these lands can become barren, and adaptive natural vegetation may disappear.

Abdalla et al. (2018) and Haba Ora et al. (2020), report that high grazing intensity has significant impacts on soil quality decline, including reductions in organic carbon storage and other soil quality indicators, which indirectly reflect pasture degradation due to intensified grazing activities. Restoration strategies include improving botanical composition, managing grazing according to land carrying capacity, and providing rest periods for pastures.

Riwu Kore & Haba Ora (2018), recommend that species diversification in pastures should maintain a standardized grass-to-legume proportion of 2:3, or 40% grasses to 60% legumes. Riwu Kore et al. (2021), legume dominance functions to increase forage protein content and improve soil fertility through nitrogen fixation, while grasses help maintain biomass production stability and ground cover, thereby supporting the productivity and sustainability of grazing systems.

Climatic and Edaphic Approach

Environmental factors, such as climatic and edaphic elements, can act as limiting factors for livestock production systems. Climate is a combination of temperature, air humidity, rainfall, airflow/movement, radiation conditions, barometric pressure, and ionization. A pasture is considered suitable for supporting livestock production when it has 70% humidity, solar radiation between 60–80%, wind speed of 5–7 knots, evaporation of 150–200 mm, and a temperature of 27°C (Haba Ora, 2015). de Souza et al. (2019), the ideal conditions for livestock grazing in pastures are temperatures ranging from 10–20°C with 60–80% humidity. The effects of climate are particularly evident in pastures located in regions with distinct wet and dry seasons.

Haba Ora et al. (2020), report that tropical pastures during the middle and end of the rainy season are dominated by short, creeping, and medium-height grass species rather than legumes. During the dry season, temperature and humidity increase, wind speed rises, solar radiation becomes more intense, and soil evaporation increases. Conversely, in the rainy season, solar radiation intensity, wind speed, and evaporation decrease. Under such climatic conditions, pastures are dominated by grasses and shrubs with limited vegetative growth and a short generative phase. The optimal climatic influence on pasture quality in tropical areas occurs only for a short duration.

In tropical regions such as Indonesia, the average monthly rainfall is 160.15 mm (classified as dryland with an annual rainfall of <1,500 mm), which can support the growth of pasture grasses such as *Brachiaria* species.

Carrying Capacity

Carrying capacity refers to the ability of a pasture to produce sufficient forage to meet the needs of a certain number of livestock grazed per hectare. Haba Ora & Riwu Kore (2017), carrying capacity is the number of animals that can be maintained per unit area of pasture. Li et al. (2025), define carrying capacity as the optimum stocking rate of livestock for a given area. Pasture carrying capacity can vary due to climatic, edaphic, and topographic influences. Costa et al. (2021) note that forage production in pastures is closely related to defoliation and grazing pressure (grazing intensity). Li et al. (2025), state that estimates of pasture carrying capacity depend on the number of livestock, feeding methods, forage production, and livestock age. Meanwhile, Fuah et al. (2021) emphasize that carrying capacity should consider grazing and rest periods, daily forage intake, and forage consumption per hectare.

Haba Ora (2015) defines livestock standards for carrying capacity in terms of livestock units (LU), which are standardized based on the relationship between body weight and feed consumption, as presented in Table 1.

Table 1. Livestock Unit (LU) Standards

No.	Livestock	Age Groups	Age (Year)	Livestock Unit (LU)
1	Cattle/Dairy	Bull/Cow	>2	1,00
		Steer/Heifer	1-2	0,50
		Calf	<1	0,25
2	Buffalo	Bull/Buffalo Cow	>2	1,00
		Young Bull/Heifer	1-2	0,50
		Calf	<1	0,25
3	Sheep	Buck/Doe	>2	1,00
		Buckling/Doeling	1-2	0,50
		Kid	<1	0,25
4	Goat	Ram/Ewe	>2	1,00
		Ram Lamb/Ewe Lamba	1-2	0,50
		Lamb	<1	0,25

Source: Haba Ora, 2015

Based on Table 1, it is determined that forage requirements by age group for livestock are as follows: adult ruminants (1 LU) require 35 kg of forage per head per day, young ruminants (0.5 LU) require 15–17.5 kg/head/day, and juveniles require 7.5–9 kg/head/day. This is because livestock type is closely related to their feed consumption needs. The estimation of forage requirements is based on the relationship between pasture carrying capacity, livestock type, forage production, season, and the area of the pasture. Accordingly, carrying capacity can vary depending on forage production, particularly between the rainy and dry seasons. Riwu Kore & Haba Ora (2018) define a pasture as productive if the livestock carrying capacity reaches a minimum of 2.5 LU/ha/year with a grass-to-legume composition of 60:40. Marnisah et al. (2022) note that such conditions reflect a balance between available forage and the number of livestock units per unit of time.

Several factors need to be considered in determining pasture carrying capacity, including estimating forage production quantity, determining the proper use factor (PUF), calculating monthly land requirements, and estimating annual land requirements (Haba Ora, 2015; Riwu Kore & Haba Ora, 2018).

1. Estimating forage production quantity. The most common method is the plot-frame sampling method using frames of specific sizes and shapes (square, rectangular, circular, or triangular). Sampling is conducted randomly. Land homogeneity should be considered in terms of botanical composition, production distribution, and topography. Forage within the selected frame area is cut at approximately 5–10 cm above ground level, then weighed.
2. Proper Use Factor (PUF). The PUF depends on the type of grazing livestock, forage species, soil condition of the pasture, and the local climate type. PUF estimation for pastures is divided into three levels: light (25–30%), moderate (40–45%), and heavy (60–70%). Differences in PUF are influenced by several factors:

- Soil erodibility, where areas prone to erosion or with low vegetation cover should not have excessive forage harvested.
- Forage regenerative pattern, where pastures with slow post-harvest regrowth should not have all forage considered available for grazing.

- Type and estimated number of livestock, as a higher number of animals means trampling may prevent 100% of forage from being consumed.

3. Estimating monthly land requirements. This estimation is based on livestock forage consumption capacity. For example, if an adult cattle consumes 40 kg of forage per day (approximately 10% of body weight), the monthly requirement would be 40 kg × 30 days = 1,200 kg (1.2 tons) of forage per month. If forage production is 8 tons per hectare, the land area required per adult cow per month is 1.2 tons ÷ 8 tons/ha = 0.15 ha.
4. Estimating annual land requirements. Pastures require a regrowth period after grazing, known as the rest period. Tropical pastures require 70 days of rest following 30 days of grazing. Annual land requirements can be estimated using the principle of rational grazing (Voisin Grazing), expressed as: $(y-1)s = r$.

Where:
y = Conversion factor of land area Required per year from monthly requirements
s = Grazing period
r = Rest period

Carrying Capacity Index

Carrying capacity is intended to support sustainable development. Duku et al. (2025), carrying capacity refers to the ability of a pasture to provide fresh or dry forage without processing and/or additional supplementation for grazing livestock, with limiting factors including climatic and edaphic conditions as well as patterns of human technological intervention.

Carrying capacity is estimated using the Carrying Capacity Index (CCI), which is the ratio of total pasture forage production to the forage requirements of grazing livestock. The CCI value reflects whether the available forage in the pasture is sufficient to meet livestock consumption needs. Riwu Kore & Haba Ora (2019b) define four criteria for evaluating the CCI:

1. $\text{CCI} \leq 1$ – Highly Critical Area. Livestock have no preference in utilizing the available forage resources, leading to depletion of agroecosystem resources. Vegetation and its residues are unable to complete their natural cycles.

2. CCI > 1 – 1.5 – Critical Area. Livestock show some preference in utilizing resources, but conservation aspects are not yet adequately addressed.
3. CCI > 1.5 – 2 – Vulnerable Area. The development of organic matter in the environment is limited and marginal.
4. CCI > 2 – Safe Area. Forage resources are functionally sufficient to meet livestock needs while maintaining environmental efficiency.

Other literature classifies the Carrying Capacity Index (CCI) into four categories: highly critical area (CCI < 2), critical area (CCI > 2–3), vulnerable area (CCI > 3–4), and safe area (CCI > 4). Differences in these classifications are influenced by other utilization factors, such as technological and human interventions, which result in either actual carrying capacity or potential carrying capacity (Haba Ora et al., 2020).

Actual carrying capacity refers to the ability of a pasture to provide fresh or dry forage, without processing or additional supplementation, that can be directly consumed by grazing livestock. In contrast, potential carrying capacity refers to the capacity of forage in the pasture that has the potential to be developed, cultivated, and managed through practices such as pruning, improved planting patterns, shade trees, intercrops, fencing plants, soil and water conservation, and production enhancement.

Estimation of the carrying capacity index for grazing livestock, such as beef cattle, is calculated based on the annual requirement of one livestock unit (LU), where the forage requirement = livestock population (LU) × 1.14 tons of Digestible Dry Matter (DDM)/year (generally, 1 adult LU = 250 kg).

$$\text{CC (LU)} = \frac{\text{DDM Production (kg)}}{\text{DDM Requirement of Adult Cattle (kg/LU)}}$$

The CCI value is calculated based on DDM using the following equation:

$$\text{CC (LU)} = \frac{\text{DDM Production (kg)}}{\Sigma\ \text{Ruminant Population x DDM Requirement of Adult Cattle (kg/LU)}}$$

or

$$\text{CCi (LU)} = \frac{\text{Forage Carrying Capacity (LU)}}{\Sigma\ \text{Ruminant Population (LU)}}$$

Forage production for each suitability class is assumed as follows: S1 = 80%, S2 = 60%, and S3 = 40%, while class N is not considered.

The characterization of crop residue feed and the potential forage on each land use type are presented in Table 2 and Table 3.

Table 2. Characterization of crop residue feed

No.	**Type of Crop Residue**	**Residue Production (ton/year)***	**Digestibility**	**Digestible Dry Matter Production (ton)**
(a)	(b)	(c)	(d)	(e)
1	Irrigated rice	9.0	0.140	(c) x (d)
2	Rainfed rice	6.6	0.140	(c) x (d)
3	Maize	15.0	0.150	(c) x (d)
4	Green beans	1.9	0.137	(c) x (d)
5	Sweet potato	2.5	0.135	(c) x (d)

Source: Haba Ora, 2015 *Estimated optimum production

Table 3. Characterization of potential natural feed resources by land use

No.	**Land Use**	**Area (ha)**	**Natural Feed Productivity (ton/ha/year)**	**Production (DDM/ha/ton)**
(a)	**(b)**	**(c)**	**(d)**	**(e)**
1	Rice fields			
	– Galengan (dry agroclimate)	(-)	0.125	(c) x (d) x 0.5**
	– Bera (double cropping)	(-)	0.500	(c) x (d) x 0.5**
2	Rainfed upland rice			
	– Galengan (dry agroclimate)	(-)	0.125	(c) x (d) x 0.5**
	– Bera (double cropping)	(-)	0.500	(c) x (d) x 0.5**
3	Mixed garden*	(-)	0.300	(c) x (d) x 0.5**
4	Shrubland (dry agroclimate)	(-)	1.000	(c) x (d) x 0.5**
5	Others / open land*	(-)	0.750	(c) x (d) x 0.5**

Source: Haba Ora, 2015 **) Digestibility is accounted for at 50% of DDM

The calculation of ruminant livestock population in Livestock Units (LU) is based on the LU values of major ruminant livestock, as presented in Table 4.

Table 4. Nilai satuan ternak (ST) ruminansia

No.	**Livestock Type**	**Total Population**	**Conversion Factor***	**Total (LU)**
(a)	**(b)**	**(c)**	**(d)**	**(e)**
1.	Cattle/Dairy	(-)	0.7	(c) x (d)
2.	Buffalo	(-)	0.8	(c) x (d)
3.	Goat/Sheep	(-)	0.055	(c) x (d)
Total		(-)		(-)

Source : Haba Ora, 2015. *Conversion factor used to standardize livestock to one Livestock Unit (LU)

Livestock carrying capacity is determined through calculations of land area and the carrying capacity of each land-use type.

Ruminant Livestock Population Growth Capacity (RLPGC)

The capacity of a region to provide livestock feed can be analyzed using the KPPTR method as an approach to assess the potential of the area. The equivalence rules and assumption values from Nell & Rollinson are applied in this method. This potential can be expressed either as feed potential (tons of Digestible Dry Matter per year) or as the actual carrying capacity, i.e., the number of livestock units (LU) that the area can support.

Furthermore, the capacity for ruminant population growth in a livestock area can be estimated if the existing ruminant population is known. In densely populated areas, the effective limiting factor for increasing ruminant populations is land resources, whereas in sparsely populated areas, the number of livestock-owning households acts as the effective constraint.

The formula for estimating the Ruminant Livestock Population Growth Capacity is generally expressed as the difference between land carrying capacity and the existing livestock population, in Livestock Units (LU):

Ruminant Livestock Population Growth Capacity (RLPGC) = Land Carrying Capacity (LCC) – Existing Population (EP)

Explanation:

LCC (LU) = Maximum number of livestock (in LU) that the land can sustainably support

EP (LU) = Current ruminant livestock population

RLPGC (LU) > 0 : There is still potential for population increase

RLPGC (LU) = 0 : Population is already optimal

RLPGC (LU) < 0 : Overstocking occurs

If LCC is calculated based on forage production, the operational formula is often derived as:

$$\text{LCC (LU)} = \frac{\text{Forage DDM production (kg/year) x Utilization coefficient}}{\text{DDM requirement per LU (kg/year)}}$$

Calculation of Location Quotient (LQ)

The LQ method is an analytical tool used to determine whether a region functions as a basic or non-basic sector in the livestock population (Sembiring et al., 2025). Haba Ora (2015), the LQ method serves as an economic model to understand the growth of activity sectors that can stimulate regional development. Riwu Kore & Haba Ora (2018), define a basic sector as one that produces goods or services that can be exported or sold outside the local community, bringing income from outside into the region, while non-basic activities only meet local needs and do not generate external surplus

Himmah & Priana (2025), note that for land-based commodities, the LQ method is calculated using planted area, harvested area, and production area, whereas for non-land-based commodities such as livestock, the LQ calculation is based on the number of animals in the population.

The LQ method is formulated as follows:

$$\text{LQ} = \frac{(vi/vt)}{(Vi/Vt)}$$

Explanation:

vi = Beef cattle population in the sub-district

Vt = Number of households in the sub-district

Vi = Beef cattle population in the district

Vt = Number of households in the district

If the LQ of a sector is greater than or equal to 1 (≥ 1), the sector is considered a basic sector. Conversely, if the LQ of a sector is less than 1 (< 1), the sector is considered a non-basic sector.

The distribution pattern of ruminant livestock is measured using the Livestock Concentration Index (LCI). The LCI is calculated based on the ratio of the livestock population in a sub-district (Pkec.) to the average sub-district population within the district/city (Pkota.). The categories for the Livestock Concentration Index are:

LCI > 1: dominant or above-average population

LCI 0.5–1: average population

LCI < 0.5: low or minimal population

The estimation of agricultural residue production across regions is carried out using the Agricultural Residue Concentration Index (ARCI). The ARCI is the ratio of agricultural residue production in a sub-district to the average sub-district production within the district/city. The categories are:

ARCI > 1.0: high (above average)

ARCI 0.5–1.0: average

ARCI < 0.5: low

Pasture Production

Generally, pastures and agricultural lands in tropical regions produce forage of low quality. Therefore, land improvement in tropical areas is recommended through the following measures:

- Optimization of macro-elements, such as nitrogen (N) and phosphorus (P), as well as other elements according to the minimum plant requirements, through fertilization.
- Introduction of superior forage species, such as grasses (elephant grass, king grass, Bengal grass, etc.) and/or legumes (lamtoro, gamal, turi, and other adaptive types) that are productive, persistent, and tolerant to grazing pressure.
- Introduction of shrubs or multipurpose trees (MPTs) as a source of concentrate feed when forage is limited, as well as for nutritional improvement efforts. The introduction of plants or shrubs must consider the planting time (early rainy season), fertilization, regulation of defoliation intervals, and pruning techniques or cutting height from the soil surface (approximately 15 cm or leaving 2–3 nodes/stems).

Pastures in tropical regions require rejuvenation. Haba Ora et al. (2020), during the dry season, livestock body weight in pastures can decrease by 30–60 kg due to overgrazing accompanied by insufficient forage in both quantity and quality. Riwu Kore et al. (2020), reported that forage quality in dryland areas, such as Timor Island, East Nusa Tenggara Province, Indonesia, is very low, characterized by crude protein content of 3.8% and cell wall content of

85% during the dry season, with slight improvement in the rainy season to 5.8% crude protein and 65% cell wall content.

The low quality of pastures in dryland areas such as East Nusa Tenggara Province is linearly associated with a decline in forage quality. Chauhan et al. (2023), found that water deficit in forage significantly disrupts plant physiological processes; for example, photosynthetic rate decreases due to stomatal closure reducing CO_2 uptake, while cellular respiration continues, causing changes in metabolite metabolism and distribution. These effects often result in a relative increase in cell wall components and structural changes in cells, contributing to reduced forage productivity and quality under drought conditions.

In some tropical regions of Indonesia, the dry season is not a critical issue because deficits in forage quantity and quality are mitigated through interventions such as the introduction of legumes, supplementation by sourcing or purchasing feed from other areas, or irrigation.

Livestock Farmer Human Resources

Human resources among livestock farmers are a crucial aspect for the productivity and efficiency of pastures in utilizing real and potential carrying capacity to support ruminant livestock production systems. The capacity of livestock farmers can vary across regions due to individual characteristics, which generate diverse motivations and priorities.

Adler et al. (2019), farmers' attitudes and personalities contribute to decisions regarding livestock management, animal health, and productivity, reflecting differences in individual characteristics among farmers. Nkonki-Mandleni et al. (2019), reported that farmers' socio-economic characteristics, such as location, household size, experience, and access to training, influence their ability to manage livestock production. Balzani & Hanion (2020), noted that farmers' knowledge, empathy, and personal traits are internal factors affecting attitudes and farming practices, highlighting variations in goals and capabilities among farmers.

The variables for determining the capacity of livestock farmers as human resources are assessed based on the following aspects:

1. Farming experience, categorized as less than 5 years, between 5 and 10 years, and more than 10 years;
2. Formal education of the farmers;
3. Non-formal education of group member farmers;
4. Literacy skills (ability to read and write) of group member farmers; and
5. Communication intensity of the farmers.

The five points mentioned above are interrelated. Papadopoulos et al. (2021), reported that the average age of productive livestock farmers is 46 years (ranging from 28–65 years), while Riwu Kore & Haba Ora (2018), indicated that the productive age of farmers ranges from 15–65 years, with an average of 40 years. Farmers in their productive period are generally capable of creative thinking and working, and are able to adopt technology to support livestock production systems. Besides age, low educational levels among farmers negatively affect the speed of adaptation to innovations and technology, resulting in weak supervision and management of production systems. The type of occupation and family responsibilities can also hinder livestock productivity, especially when farming is conducted as a conventional and part-time activity, and family obligations, while providing labor, can become a burden. Farmers are considered experienced if they have been running livestock enterprises for 3–22 years, with an average of 11 years, as they acquire technical skills and the ability to adopt technological innovations. According to Riwu Kore & Haba Ora (2019b), the scale of the enterprise is related to income, based on the number of livestock owned: small scale (1–5 animals), medium scale (6–10 animals), and large scale (>10 animals).

In addition to farmer characteristics, livestock production is also supported by institutions and their interactions as social resources, either in the form of farmer groups or associations of farmer groups. These social resource variables are assessed based on the following criteria.

1. Collaboration in feed provision, categorized as absent or present;
2. Collaboration in capital provision, categorized as absent or present;
3. Collaboration in disease control, categorized as absent or present;
4. Collaboration in marketing of products, categorized as absent or present;

5. Meetings among group members, categorized as less than once per month or at least once per month;
6. Collaboration with other institutions, categorized as absent, with 1–2 institutions, or with more than 2 institutions; and
7. Mastery of diversification technology.

Ouédraogo et al. (2025), reported that the location of livestock institutions influences strategies for providing feed to livestock. In institutions based on agriculture, the main sources of livestock feed come from agricultural residues, such as rice straw and/or maize stover. Meanwhile, in highland or agroforestry areas, feed is primarily obtained from forest products and fodder trees.

Supporting Facilities

The availability of supporting service facilities for the livestock production system is necessary to sustain the system. Service capacity consists of high-priority services (Poskeswan, Pos IB, inseminators, PPL/KCD); medium-priority services (breeder farmer groups, livestock markets, veterinary drug traders); and low-priority services (holding grounds, veterinary laboratories, slaughterhouses, and livestock product processing industries).

CONCLUSION

The agroecosystem approach in tropical drylands emphasizes that pasture management cannot be separated from the interactions among land's biophysical components, climate, vegetation, livestock, as well as technological and human management interventions. Land carrying capacity, as a key indicator of sustainability, is strongly influenced by the availability and quality of forage, climatic and edaphic suitability, and the grazing patterns applied. Therefore, the application of agrotechnology principles—including vegetation management, soil and water conservation, forage diversification, and crop–livestock integration (agropasture)—is essential for enhancing productivity while maintaining ecological balance. This approach is expected to provide a basis for planning and policymaking in the development of productive, adaptive, and sustainable ruminant livestock systems in tropical dryland areas.

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CHAPTER 2

THE GREEN DILEMMA OF SOLAR-DRIED KITCHEN WASTE AS SUSTAINABLE POULTRY FEED

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INTRODUCTION

The Global Waste Crisis

The issue of municipal solid waste pollution has become one of the most acute problems of the twenty-first century. Studies show that the production of municipal solid waste is directly proportional to the size of the city, meaning that the production of increasingly larger amounts of waste is directly proportional to the size of the population and its urbanization (Lu et al., 2024). Municipal solid waste generates more than 2 billion tonnes every year globally, posing significant problems to waste management facilities, environmental conservation, and sustainability (Yatoo et al., 2024).

The composition of municipal solid waste differs greatly by region but organic materials (especially kitchen waste) always make up the largest proportion. In most cities, organic kitchen wastes make up 40-60 percent of the total municipal solid wastes. High moisture content (usually 70-85%), quick degradable properties, and high putrescibility are the main characteristics of this organic fraction that makes it highly challenging to dispose of and to be easily removed by the traditional ways of waste disposal, including landfilling and incineration (Zhang et al., 2024).

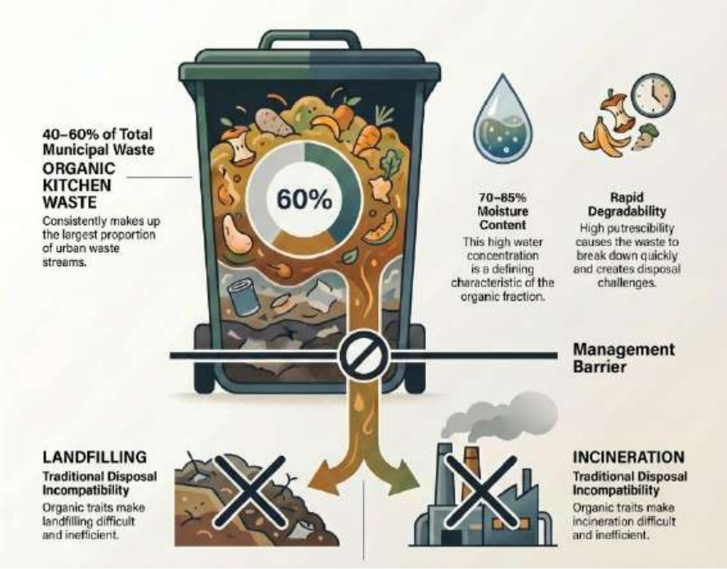

Figure 1: The challenge of organic municipal waste

Environment Impact of Organic Waste Disposal

The consequences of not properly disposing of organic waste on the environment go way beyond the visual and olfactory irritations of piles of waste. The deposition of organic waste in landfills leads to an anaerobic process, which generates methane a greenhouse gas that is about 28 times stronger than carbon dioxide in the course of 100 years. One of the biggest anthropogenic sources of methane emission to the atmosphere worldwide is landfills, which contribute to climate change (Kiehbadroudinezhad et al., 2024).

Moreover, the development of leachate, the contaminated liquid, formed as a result of the water being infiltrated into waste products, is very dangerous to the quality of soil and groundwater. Landfill leachate has many contaminants such as heavy metals, organic compounds, and pathogenic microorganisms, which may penetrate the groundwater sources, posing long-term health risks to the local communities (Fida et al., 2024). Levels of heavy metal in water samples in the vicinity of dumpsites were often higher than those recommended by the World Health Organization, showing that the issue of poor waste management has continued to be an environmental legacy. The synergistic effect of methane emissions and contamination of groundwater highlights the importance of seeking sustainable waste management options that will redirect organic waste out of landfills as well as achieve value recovery of such materials (Alao et al., 2025).

Methane from anaerobic decomposition is significantly more effective at trapping atmospheric heat than carbon dioxide.

Rainfall filters through waste, creating a toxic liquid that transports pollutants into soil and groundwater.

Heavy metal concentrations near waste sites frequently surpass World Health Organization safety guidelines.

PRIMARY HAZARDOUS COMPONENTS IN LEACHATE

Contaminant Category	Primary Risks
Heavy Metals	High concentrations exceeding international health safety standards.
Organic Compounds	Diverse chemical substances derived from decomposing waste matter.
Pathogenic Microorganisms	Disease-causing agents that threaten biological safety and local water.

Systemic reform must prioritize redirecting organic waste away from traditional landfilling to halt contamination.

Transforming organic waste into useful resources to capture economic and energetic utility.

Solutions must address both atmospheric and groundwater impacts simultaneously to protect local communities.

Figure 2: Impacts of the Organic Waste Disposal

Poultry industry and Feed Cost difficulties

In line with the crisis of waste management, the world of poultry is experiencing economic strains unprecedented. The use of poultry as an animal protein source has become more significant to satisfy the increasing population of people all over the world (Nirmal et al., 2025). Poultry production is crucial in terms of providing nutritional security, sustaining rural livelihoods and economic growth, especially in the developing countries (Kashyap et al., 2024; Wongtangtintharn et al., 2025).

Nonetheless, a major economic question faced by poultry producers is that the cost of feed accounts for 60-70% of the overall production costs (Ramankevich et al., 2025; Ogundej et al., 2025; Vidanapathirana et al., 2025). The increasing price and volatility of traditional feed ingredients, especially maize, soybean meal, and fish meal, have presented the industry with great sustainability issues (Iheanacho et al., 2025). Crops, market forces, geopolitical instability, and disruptions in supply chains have increased the lack of feeds and price volatility due to climate change (Deb, 2025; Zolotnytska et al., 2025).

Circular Bioeconomy Paradigm

The waste management crises coupled with the need to manage feed costs have spurred excitement to valorize organic waste in the kitchen as an alternative feed source as a part of the concept of the circular bioeconomy. Circular bioeconomy concept advocates the transformation of food wastes into renewable resources, which minimize environmental footprints, and generate economic value (Pal et al., 2024; Sharma et al., 2025).

Food waste valorization as a sustainable strategy to food waste management and improve food security, resource conservation, environmental impacts, and the circular bioeconomy. Nonetheless, there are still considerable obstacles in the way of translating this theoretical possibilities into practice, making them safe and economically feasible (Nath et al., 2023).

1. ORGANIC KITCHEN WASTE: COMPOSITION, GENERATION, AND VALORIZATION POTENTIAL

Global Generation Trends

The amount of waste produced by kitchen that is being produced around the world is astounding and it is on the increase. The amount of waste in the world will amount to 3.40 billion tonnes each year, organic kitchen waste will constitute the biggest and the fastest-growing portion (Chandrappa and Das, 2024). The rate of municipal solid waste production is rising at worrying levels across the world alongside population growth and urbanization, which requires sound policies on how to manage the ever-increasing crisis (Sarker et al., 2025). In 2023, the amount of waste generated in the kitchen in China was about 60 to 92.4 million tonnes, and the amount in the world was about 1.3 billion tonnes (Xiong et al., 2023).

Compositional Variability

Kitchen waste composition differs greatly based on the source, geographic place, season, cultural activities, and socioeconomic influences. This fluctuation is one of the inherent problems of waste valorization, where it is required to have uniform feedstock properties in order to predictable processing results. Common items of waste in a kitchen include:

- Fruit and vegetable peels, cores and trimmings.
- Food leftover cooked and uncooked.
- Small bones and eggshells.
- Grounds of tea and coffee.
- Waste of bread and bakery.
- Minimal quantities of meat and fish-wastes (Xiong et al., 2023).

Kitchen waste, which is mainly plant-based waste, is a good source of macronutrients and micronutrients, which include bioactive substances such as: antioxidants, flavonoids, anthocyanins, tannins, carotenoids, and plant sterols. These compounds are associated with a number of health advantages, but their sensitivity with regard to processing methods has led to the need to be cautious when choosing treatment methods (Zubair et al., 2023).

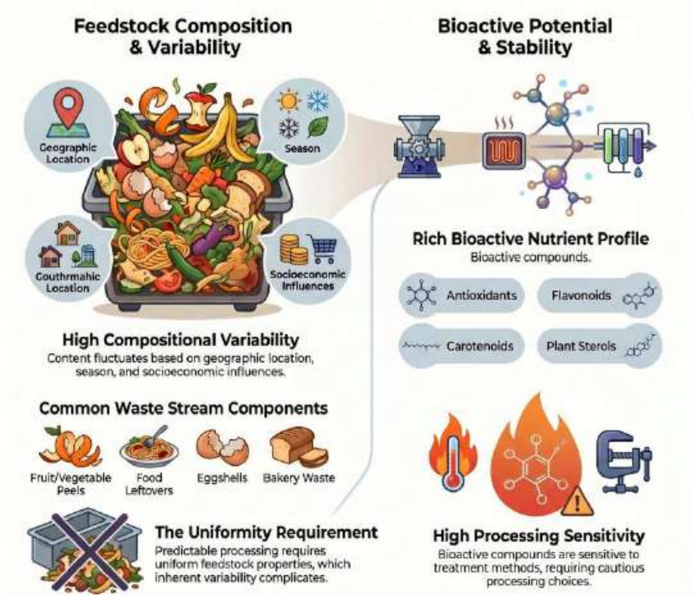

Figure 3: Kitchen waste valorization: composition and processing challanges

Nutritional value of Kitchen Waste

Although it is said to be waste, the organic kitchen waste has a high nutritional value that can be potentially reused to feed animals. Food waste could have a higher protein content compared with the conventional poultry rations, but there is a high level of variability (Garnida et al., 2022). The poultry feeds based on fruit waste and restaurant leftovers had more protein and fat than commercial feed, which indicated a potential as alternative, inexpensive poultry feed ingredients (Tafida and Bashir, 2024).

Bioactive Compounds of Kitchen Waste

In addition to the essential nutrients, the waste in the kitchen has other bioactive compounds that have the potential to perform functional properties. The fruit and vegetable waste, such as stems, stalks, and peels, can be good sources of dietary fiber, antioxidants, vitamins, and minerals. Anti-cancer, antimicrobial, antiviral, anti-inflammatory activities and prevention of a variety of disorders have been linked with these compounds (Yilmaz and Pehlivan, 2024).

2. POULTRY INDUSTRY: NUTRITIONAL NEEDS AND FEED FORMULATION

Economic Importance of Poultry Production:

The poultry industry has grown to be a key constituent in the food systems of the world offering billions of consumers around the globe with cheap and quality protein. Poultry production has a positive impact on food security, rural incomes, and economic growth in developing countries, especially in developing countries (Kashyap and Goswami, 2024; Fadilah et al., 2025). Economic viability of the industry is however heavily reliant on the cost of feed. Feed costs are indeed the biggest single cost in poultry production as recorded by 60-70 per cent of the overall production costs. Any plan that has the ability to lower the cost of feeds and yet retain or even increase the production efficiency can revolutionize the economics of poultry (Ramankevich et al., 2025).

Conventional Feed Ingredients

Traditional poultry feeds are developed around a number of primary nutrients that contain some basic nutrients. Maize is recognized as a good source of energy, palatable, and it lacks anti-nutritional components. Soybean Meal is the main source of protein and it will be used to produce essential amino acids that will be required to sustain growth, feather development and egg production. Fish Meal is also a good source of protein-rich in essential micronutrients and omega-3 fatty acids. Vitamin-Mineral Premix is important to cover the micronutrient needs of the poultry and assist in different physiological functions such as bone formation, immune system and reproduction (Bauer et al., 2025).

Alternative Feed Sources

The escalating costs and sustainability issues relating to traditional feed materials have enhanced intensive research on alternative feed materials. The importance of the alternatives such as plant-based by-products, insect meals, agro-industrial residues, and food waste as possible sustainable alternatives to maize and soybean meal.

There are a number of possible benefits to alternative feed sources like less competition between animal feed and human food, smaller carbon footprints than the traditional ingredients, local production possibility, cutting vulnerability to supply chains, and conformity to the ideals of the circular economy (Bhosale et al., 2025).

Poultry Nutritional considerations

The nutritional needs of poultry with the alternative source of feed have to be met with proper attention to various factors. It is essential to optimize protein consumption and ratios of amino acids to enhance chicken performance and minimize adverse effects on the environment. High amount of crude protein raises the cost of feed and nitrogen secretion, posing environmental issues. The supplement of non-bound amino acids in poultry diets has facilitated that the levels of the crude protein can be reduced without affecting the performance (Chathuranga and Heo, 2025).

The need to implement measures that enhance the digestibility of nutrients, gut health, and feed efficiency. Vitamins (especially B-complex vitamins) and minerals (phosphorus, magnesium, iron) are critically involved in the metabolism of energy. Exogenous carbohydrates, phytases, proteases, and prebiotics can also be used as feed additives to enhance the utilization of nutrients and ferment the substrates to minimize anti-nutritional factors (Raut et al., 2024).

3. WASTE PROCESSING CLEAN AND GREEN TECHNOLOGIES

Solar Drying Technology

One of the most suitable ways to manage food waste is drying because dried foods can be used as animal feed, and food waste is reduced, and at the same time, useful resources are obtained. Among the more promising technological solutions to the developing countries, where the sun is abundant and traditional energy sources are scarce, solar drying has appeared (Deymi-Dashtebayaz et al., 2024).

Solar-assisted drying shortens the drying time and boosts the drying rates with high-quality dried products as its result.

Solar dryers which are hybrids have been found to be helpful especially in ensuring that good drying rates are attained without compromising the quality of the product. The basic concept of solar drying is the greenhouse effect: the solar radiation is received and absorbed by the material one wants to dry by passing through a transparent cover (usually glass or plastic). The hot material emits moisture that is transported by the ventilation air. Drying efficiency can be greatly increased by proper design, such as the right cover angle (usually 45°), sufficient ventilation and thermal mass to store heat (Boateng, 2023).

Table 1: Comparison of solar drying with other drying technologies in processing organic waste.

Technology	**Energy Source**	**Operating Cost**	**Product Quality**	**Environmental Impact**	**Suitability for Developing Countries**
Solar Drying	Solar (renewable)	Low	Moderate	Very low	High
Electric Drying	Grid electricity	High	High	Moderate (depending on electricity source)	Low
Freeze Drying	Electricity	Very high	Very high	High	Very low
Microwave Drying	Electricity	Moderate	High	Moderate	Low
Thermal Drying	Fossil fuels	Moderate	Moderate	High (CO_2 emissions)	Moderate

The environmental effect of a solar drying unit to convert food waste into animal feed, reporting that the overall carbon footprint of the treated food waste was about 217.5 kg CO_2 eq. per ton. Operation stage was the major contributor to the environmental impacts because of the use of electricity to ventilate the building. Drying of the solar drying unit recorded an average of 80% weight reduction, which indicates that using solar drying to reduce the volume of wastes is a possibility (Abeliotis et al., 2022).

Alternative Drying Technologies

Although solar drying has its benefits when applied in developing countries, other types of drying technologies can be suitable in other settings:

Freeze Drying: It is the most suitable process since it produces the best products but consumes a lot of energy and is very costly and can only be applied to high value products.

Microwave Drying: Provides quick drying and fine quality of products but needs a consistent supply of electricity and is more expensive to run as compared to solar drying.

Thermal Drying: Is a process that uses fossil fuels to produce heat to aid in the drying process and has great reliability in its operation despite the weather conditions at a high cost in terms of carbon emissions and fuel prices.

Bio-Drying: A new technology that relies on aerobic decomposition to produce biological heat to power moisture removal with minimum external inputs (Xu et al., 2024).

Solid-State Fermentation as an Accomplishing Technology.

Solid-state fermentation (SSF) has become a promising alternative technology to improve the nutritional quality and safety of animal feed using organic waste. SSF is one of the options to convert solid waste into value-added bioproducts and underline its ability to use a wide range of organic waste materials as the starting material (Oiza et al., 2022).

Pineapple wastes SSF, which resulted in improved antioxidant activity and free phenol content, enhancement of enzyme activities such as 2-glucosidase, and modification of phenol composition. These results indicate that SSF may have the potential to:

- Reduce anti-nutritional factors
- Enhance nutrient bioavailability
- Synthesize useful bioactive substances.
- Improve palatability
- Reduce pathogen loads (Paz-Arteaga et al., 2023)

4. SAFETY AND QUALITY CONSIDERATIONS FOR FOOD WASTE-BASED FEEDS

Microbial Contamination Risks

The possibility of microbial contamination is one of the most important issues of food waste-based feeds. Mahunu et al. (2024) noted the necessity of safe food handling to avoid microbial contamination, and Sharma et al. (2025) pointed to the issue with bioconverting kitchen waste because of the differences in pH and chemical structure. The use of the source-separated dried food waste in poultry feed and discovered that microbial analysis revealed bacteria and fungi presence on the feed, which indicated low-quality feed. This finding underscores the importance of adequate processing to ensure microbial safety (Ayim et al. 2025).

Disease transmission by contaminated feed, such as prions, endoparasites, and pathogenic bacteria, has been effectively controlled by thermal treatment procedures and quality control. Nevertheless, the recent outbreaks of viruses, including Porcine Epidemic Diarrhea Virus and African Swine Fever Virus, in other countries have shown that high levels of biosecurity are necessary to prevent and control the spread of viruses via feedstuffs (Shurson et al., 2022).

Chemical Contaminants and Anti-Nutritional Factors

Food waste chemicals (such as heavy metals, pesticides, mycotoxins and processing contaminants) are also a source of further safety issues. Microwave processing has the ability to mitigate the anti-nutritional components in food grains. In the same manner, food waste has been reported to be cleansed of toxic metal elements such as cadmium and arsenic through drying which makes it safer to consume poultry (Suhag et al. 2021).

Physical Hazards

Physical risks in food waste such as bones, shells, plastic fragments, glass, and metal fragments may cause direct damages to animals and damage processing devices. Proper sorting and screening should also be done to eliminate physical hazards prior to processing (Van Raamsdonk et al., 2023).

Nutritional Variability

Probably the most difficult thing with the use of food waste as animal feed is the uncontrollable changes in nutritional content. Plant-based and animal-based food loss and waste could be utilized in livestock feed, yet the discrepancy in the nutrient loads and the quality is a serious problem in feed quality. One of the solutions to these issues that has been proposed by the authors was the incorporation of different food waste streams Boumans et al. (2022). Composting is one of the approaches of converting food waste into organic fertilizer, but variations in nutrient content depending on feedstock composition and processing processes and the loss of nutrients (especially nitrogen) are also a significant issue. The same is the case with feed production (Mia and Zzaman, 2025).

Regulatory Frameworks

It should also develop proper regulatory frameworks on food waste-based animal feed to be safe and allow innovation. The importance of safety policies is to guarantee the quality and safety of animal feed made of food waste (Nath et al., 2023). The need of changes in European Union legislation and government support to provide access to valuable food loss and waste streams to livestock feed (Boumans et al., 2022).

CONCLUSION

The increasing amount of organic kitchen waste both poses a challenge to the environment and an opportunity resource, whereas the increasing cost of feeds to the poultry business puts pressure on the industry. This chapter discussed solar drying as an environmentally friendly way of transforming kitchen waste to poultry food. According to a case study, even though solar drying is technically possible, with 40 percent higher internal temperatures and less moisture, untreated and unsorted waste was not safe as sole feed, and lead to 100 percent poultry death in 56 days. This result highlights the fact that the objectives of the circular bioeconomy should not interfere with the well-being of animals. The way to go is not to discard the valorization of waste but to combine food safety, precision nutrition and green engineering.

Food waste-based feeds could support sustainable agriculture and overcome the pressure in waste management and cost of feed with appropriate quality control and regulations.

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CHAPTER 3

CURRENT PRACTICES AND DEVELOPMENTAL TRENDS IN ANIMAL AGRICULTURE IN WEST AFRICA: A CASE STUDY OF NIGERIA

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INTRODUCTION

Animal agriculture is a fundamental component of agricultural systems in West Africa, contributing significantly to food security, nutrition, income generation, and rural livelihoods. In Nigeria, the livestock sector is the largest in West Africa and supports millions of households engaged in cattle, sheep, goat, poultry, and pig production. The sector supplies essential animal-source foods such as meat, milk, eggs, and hides, while also serving as a financial asset and cultural resource for many rural communities (FAO, 2013; Anaso et al., 2025a-g).

Despite its importance, livestock productivity in West Africa remains relatively low compared to global standards. Production systems are predominantly traditional, characterized by low external inputs, poor infrastructure, and limited adoption of modern technologies (Anaso and Olafadehan, 2025). These systems are highly dependent on natural pasture and seasonal crop residues, making them vulnerable to climate variability, land degradation, and feed shortages. Consequently, the region faces a persistent gap between demand and supply of animal protein (Anaso and Chibuogwu, 2026).

Nigeria, as a case study, reflects these broader regional challenges. The livestock sector is dominated by extensive pastoralism and smallholder mixed crop–livestock systems. These systems are constrained by inadequate veterinary services, poor genetic improvement programs, limited access to credit, and inefficient feed utilization. In addition, the sector is increasingly affected by environmental pressures such as climate change and resource-use conflicts, particularly farmer–herder conflicts in the northern regions (Anaso and Anaso, 2025; Anaso, 2026; Anaso et al., 2026a,b).

However, the livestock sector is undergoing gradual transformation driven by population growth, urbanization, rising demand for animal protein, and policy reforms. There is increasing interest in intensification, commercialization, and modernization of livestock production systems. Emerging trends include the adoption of improved breeds, expansion of feed processing industries, integration of agro-industrial by-products into animal diets, and the application of digital technologies for livestock management (Anaso and Alagbe, 2025a-c).

Furthermore, climate change concerns have introduced new priorities such as greenhouse gas mitigation, resource efficiency, and climate-smart livestock production. These developments are reshaping the trajectory of animal agriculture in West Africa, although progress remains uneven and constrained by structural challenges.

This paper therefore examines the current practices and developmental trends in animal agriculture in West Africa, using Nigeria as a case study. It further identifies key constraints and provides insights into future directions for sustainable livestock development.

1. CURRENT PRACTICES IN ANIMAL AGRICULTURE IN NIGERIA

1.1 Extensive and Semi-Intensive Production Systems

Livestock production in Nigeria and much of West Africa is predominantly characterized by extensive production systems, which rely heavily on natural grazing resources and, to a lesser extent, crop residues. In these systems, animals are raised under minimal input conditions, with limited supplementation, housing infrastructure, or mechanized management practices. The production model is largely opportunistic and resource-dependent, meaning animal performance is closely tied to seasonal fluctuations in pasture availability, rainfall patterns, and environmental conditions.

In the extensive pastoral systems particularly prevalent in northern Nigeria livestock production is organized around transhumance and nomadic grazing patterns. Herds are moved over long distances in search of adequate pasture and water resources, especially during the dry season when forage biomass in the Sahelian and Sudanian ecological zones becomes severely depleted. This seasonal mobility is a key adaptive strategy that enables pastoral households to sustain livestock production in highly variable and often harsh climatic environments. However, it also introduces significant constraints, including weight loss in animals during migration, increased exposure to disease transmission, livestock theft, and frequent conflicts over grazing land and water points.

The dominance of crop residues as a supplementary feed resource is particularly evident during the dry season, when natural pastures are insufficient to meet the nutritional requirements of livestock. Materials such as maize stover, sorghum stalks, millet husks, and rice straw become critical feed inputs. However, these residues are typically of low nutritional quality, characterized by high fiber content, low crude protein, and poor digestibility, which ultimately limits animal productivity and contributes to low feed conversion efficiency and high methane emission intensity.

In addition to extensive systems, semi-intensive livestock production systems are increasingly emerging, especially in peri-urban and urban areas. These systems represent an intermediate form of production where animals are partially confined and receive a combination of grazing, cut-and-carry forage, and supplemental feeding, often including agro-industrial by-products and formulated concentrates. Semi-intensive systems are more commercially oriented and are commonly associated with dairy production, poultry farming, and small ruminant fattening enterprises targeting urban markets.

The proximity to urban centers provides semi-intensive producers with improved access to markets, veterinary services, and feed resources. However, these systems are constrained by high feed costs, land limitations, and increasing competition for feed ingredients. As a result, productivity improvements are often dependent on efficient feed utilization strategies and better integration of alternative feed resources such as crop residues and agro-industrial by-products.

1.2 Smallholder Dominance

The livestock sector in Nigeria and much of West Africa is overwhelmingly dominated by smallholder production systems, where individual farmers or households keep relatively small numbers of animals as part of diversified livelihood strategies. These smallholder producers typically operate under low-input, low-output systems, characterized by minimal capital investment, limited infrastructure, and reliance on family labour. Livestock in such systems often serve multiple functions beyond food production, including savings, income buffering, manure supply for crop production, and socio-cultural roles.

Within this production structure, animals are generally managed under traditional husbandry practices, with limited use of formulated rations, controlled housing systems, or systematic breeding programmes. Feed resources are primarily derived from communal grazing lands, scavenging, and seasonal crop residues. This dependence on natural and low-quality feed resources contributes to suboptimal growth rates, poor reproductive performance, and high variability in productivity across seasons.

A major constraint faced by these smallholder farmers is limited access to veterinary services and animal health infrastructure. Veterinary coverage is often inadequate, particularly in rural and remote areas, where extension services are weak and veterinary personnel are scarce. As a result, disease prevention and control are frequently reactive rather than preventive, with farmers relying on self-medication or informal drug markets. This situation is further complicated by the widespread and often unregulated use of antimicrobials, which contributes to drug resistance and treatment failures in livestock populations (Anaso et al., 2024a-d).

In addition, smallholder farmers face significant challenges in accessing improved feed resources and nutritionally balanced diets. Commercial feed ingredients are often expensive and unaffordable for low-income producers, leading to continued dependence on low-quality roughages and agro-industrial residues with limited nutritional enhancement. The absence of feed formulation knowledge and inadequate access to feed processing technologies further exacerbate nutrient deficiencies in livestock diets, thereby limiting productivity and increasing production inefficiencies.

Another critical limitation is the low adoption of modern livestock production technologies. Technologies such as artificial insemination, genetic improvement programs, precision feeding systems, automated health monitoring tools, and climate-smart production practices remain largely inaccessible or underutilized among smallholder farmers. Barriers to adoption include high costs, inadequate technical knowledge, weak extension support systems, and limited institutional capacity (Anaso et al., 2026a,b).

Collectively, these constraints result in a production environment where livestock performance is constrained by biological potential and environmental stressors rather than optimized management practices. Consequently, productivity per animal remains low, while resource use efficiency is suboptimal. However, despite these limitations, smallholder livestock systems remain highly resilient and continue to play a crucial role in rural livelihoods, food security, and income generation across Nigeria and West Africa.

1.3 Mixed Crop–Livestock Systems

The integration of crop and livestock production systems is a defining feature of agricultural practice in Nigeria and much of West Africa, reflecting a long-established mixed farming system where crops and animals are mutually dependent components of rural livelihoods. This integration is driven by both ecological necessity and economic efficiency, as it allows farmers to optimize the use of limited land resources while enhancing overall farm productivity and sustainability.

Within this system, crop production generates a wide range of by-products and residues that serve as critical feed resources for livestock, particularly during periods of feed scarcity. These include maize stover, rice straw, sorghum stalks, millet husks, and groundnut haulms, which become especially important during the dry season when natural pasture biomass is severely reduced or completely unavailable. In many smallholder and pastoral households, these residues constitute the primary or sole feed source for ruminants during feed-deficit periods, highlighting their central role in sustaining livestock populations under variable climatic conditions.

The reliance on crop residues is a direct consequence of the seasonal nature of forage availability in the region. During the wet season, animals may depend on natural pastures and cultivated fodder, but as the dry season progresses, pasture quality and quantity decline sharply. Crop residues therefore act as a buffering mechanism, bridging the feed gap and preventing severe weight loss, mortality, and reproductive failure in livestock populations. This interdependence underscores the resilience of mixed farming systems in environments characterized by climatic unpredictability.

However, despite their importance, crop residues are generally characterized by low nutritive value, particularly low crude protein content, high lignocellulosic fiber fractions, and poor digestibility.

These nutritional limitations result in inefficient rumen fermentation, reduced feed intake, and suboptimal animal performance. The high fiber content also leads to increased enteric methane production per unit of feed consumed, contributing to low feed conversion efficiency and higher greenhouse gas emission intensity in ruminant production systems.

In many cases, crop residues are fed in their raw or minimally processed forms, with limited application of improvement techniques such as urea treatment, ammoniation, silage production, or enzymatic enhancement. Consequently, their full nutritional potential remains underexploited, and livestock productivity remains constrained. Where processing is applied, it is often at a small scale and restricted by limited access to infrastructure, technical knowledge, and financial resources (Anaso, 2025a-e; Anaso, 2026a,b).

Despite these constraints, the crop–livestock integration system offers significant environmental and economic advantages. It enhances nutrient cycling by enabling the return of livestock manure to crop fields as organic fertilizer, thereby improving soil fertility and structure. It also reduces waste accumulation from crop production, contributing to more efficient resource utilization within farming systems.

1.4 Limited Genetic Improvement

Animal breeding systems in Nigeria and much of West Africa remain largely unstructured, uncontrolled, and based on natural mating practices, reflecting a traditional livestock production paradigm that has changed little over decades. In most smallholder and pastoral systems, mating occurs freely within herds or flocks without deliberate selection of superior genetic traits, planned breeding records, or systematic genetic improvement programs. As a result, reproductive management is primarily opportunistic rather than strategic, with little or no use of tools such as performance recording, pedigree tracking, or reproductive technologies like artificial insemination.

Under these conditions, genetic progress is slow and largely accidental, as there is minimal human intervention in selecting animals based on productivity traits such as growth rate, milk yield, feed efficiency, fertility, or disease resistance.

Instead, selection pressure is often based on survival ability and general adaptability to harsh environmental conditions rather than production-oriented characteristics. Consequently, genetic improvement across generations is limited, and productivity gains remain marginal.

The livestock populations in these systems are predominantly composed of indigenous breeds and ecotypes, such as the White Fulani (Bunaji), Sokoto Gudali, Red Bororo cattle, West African Dwarf goats, and Sahel sheep. These breeds have evolved over time under natural and low-input management conditions, giving them strong adaptive traits such as heat tolerance, disease resistance, ability to thrive on poor-quality forages, and resilience to climatic stress. These adaptive characteristics make them particularly suited to the challenging ecological conditions of the region, including high temperatures, seasonal feed scarcity, and endemic disease pressures (Anaso and Chibuogwu, 2026).

However, while these indigenous breeds are highly resilient, they generally exhibit low genetic potential for productivity traits compared to improved or exotic breeds. Milk yield, growth rate, carcass quality, and reproductive efficiency are typically low, which limits overall production efficiency and profitability. This trade-off between adaptability and productivity represents a central challenge in livestock genetic improvement programs in West Africa.

Efforts to introduce crossbreeding and exotic genetic material have been made in various production systems, particularly in dairy cattle and poultry sectors. However, these programs often face significant constraints, including poor adaptation of exotic breeds to local environmental conditions, inadequate management systems to support high-performance animals, and limited continuity in breeding programs. As a result, many crossbreeding initiatives fail to achieve sustained genetic improvement or are not widely adopted at scale.

Another major limitation is the absence of structured breeding infrastructure and institutional support systems. National animal recording schemes are weak or non-existent in many regions, and extension services capable of guiding farmers on genetic improvement strategies are limited. In addition, socio-cultural preferences, such as the value placed on herd size rather than productivity per animal, further discourage selective breeding practices.

1.5 Feed and Nutrition Constraints

Feed scarcity and poor feed quality represent one of the most critical and persistent constraints to livestock production in Nigeria and much of West Africa, directly limiting animal performance, system productivity, and environmental efficiency. These challenges are both seasonal and structural, arising from the strong dependence on natural pastures and crop residues, combined with limited availability of improved forage systems and formulated feeds.

A major feature of livestock feeding systems in the region is the predominance of fibrous, lignocellulosic feed resources, particularly during the long dry season. These include crop residues such as maize stover, rice straw, sorghum stalks, millet husks, and groundnut haulms, as well as mature natural grasses that have undergone senescence. While these materials are widely available and form the backbone of ruminant feeding systems, they are inherently of low nutritive value, characterized by high neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents, low crude protein levels, poor palatability, and limited digestibility (Anaso and Alagbe, 2025a-c).

The low crude protein content of these diets, often falling below the minimum requirements for rumen microbial activity, severely restricts microbial growth and fermentation efficiency. Inadequate nitrogen supply reduces the proliferation of cellulolytic bacteria responsible for fiber breakdown, resulting in slow degradation of feed and reduced nutrient extraction. This leads to poor voluntary feed intake, weight loss, reduced milk yield, delayed growth, and poor reproductive performance, particularly in ruminants.

In addition to nutritional limitations, feed scarcity is strongly influenced by seasonal feed gaps. During the wet season, pasture availability may be adequate, but as the dry season progresses, forage biomass declines rapidly, both in quantity and quality. This seasonal fluctuation creates periods of acute feed shortage, forcing animals to survive on crop residues and low-quality roughages that are insufficient to meet maintenance and production requirements.

From an environmental perspective, poor-quality fibrous diets are strongly associated with high methane emission intensity. In the rumen, high-fiber feeds promote acetate-dominated fermentation pathways, which generate large amounts of hydrogen (H_2) as a by-product. This hydrogen is subsequently utilized by methanogenic archaea to produce methane (CH_4). As a result, animals consuming low-quality, high-fiber diets tend to produce more methane per unit of feed consumed and per unit of animal product (milk or meat), compared to those consuming more digestible, nutrient-dense diets.

Furthermore, low-quality diets prolong rumen retention time, allowing extended microbial fermentation and greater cumulative hydrogen production. This increases the substrate availability for methanogenesis, thereby amplifying greenhouse gas emissions. Consequently, the inefficiency of feed utilization in these systems is not only a productivity constraint but also a major contributor to environmental degradation and climate change.

Attempts to address feed scarcity through supplementation are often limited by the high cost and low accessibility of commercial concentrates, particularly for smallholder farmers. This economic constraint reinforces dependence on poor-quality roughages. Although agro-industrial by-products and feed processing technologies offer potential solutions, their adoption remains limited due to infrastructural, technical, and financial barriers (Anaso and Dikki, 2025).

1.6 Animal Health Challenges

Disease outbreaks remain a major constraint to livestock production in Nigeria and across West Africa, largely due to weak veterinary infrastructure, limited preventive health coverage, and inadequate disease surveillance systems. The livestock sector operates within a health management framework that is often reactive rather than preventive, meaning that interventions are typically applied after disease has already spread rather than through structured prevention and early detection systems.

A key underlying issue is the insufficient veterinary service delivery system, particularly in rural and hard-to-reach areas where the majority of livestock are kept. Veterinary clinics are few, under-resourced, and unevenly distributed, resulting in poor access to professional animal health services.

In many communities, especially pastoral and smallholder systems, livestock owners rely on informal animal health providers, traditional remedies, or self-administration of drugs without proper diagnosis. This significantly increases the risk of misdiagnosis, treatment failure, and uncontrolled disease transmission.

The consequences of this weak infrastructure are reflected in the frequent occurrence of endemic and epidemic livestock diseases, including contagious bovine pleuropneumonia, peste des petits ruminants (PPR), Newcastle disease, African swine fever, trypanosomiasis, and parasitic infestations. These diseases not only reduce productivity through mortality and morbidity but also limit trade opportunities and market access for livestock products.

Compounding the problem is the widespread issue of antimicrobial misuse and overuse in animal production systems. Antibiotics are often used indiscriminately for treatment, disease prevention, and in some cases growth promotion, frequently without veterinary prescription or laboratory diagnosis. This practice is driven by factors such as limited veterinary oversight, easy over-the-counter access to veterinary drugs, and lack of awareness among farmers regarding correct dosage and withdrawal periods. The result is reduced therapeutic efficacy, treatment failures, and a growing risk of antimicrobial resistance (AMR), which poses both animal and public health threats (Anaso et al., 2025a-g).

In addition, vaccination coverage remains low and inconsistent across many livestock production systems. While national veterinary services do provide vaccination programs for priority diseases, logistical challenges, inadequate cold chain infrastructure, limited funding, and poor farmer participation often reduce the effectiveness of these programs. As a result, herd immunity is rarely achieved at scale, leaving animal populations vulnerable to recurring outbreaks.

The interaction between weak veterinary services, poor vaccination coverage, and antimicrobial misuse creates a cyclical pattern of disease persistence. Animals frequently experience subclinical infections that reduce productivity without obvious clinical signs, further lowering feed efficiency and increasing susceptibility to secondary infections. This reinforces low production outcomes and increases production costs for farmers.

From a broader systems perspective, poor animal health management also affects food safety, public health, and trade competitiveness. Zoonotic diseases and antimicrobial residues in animal products pose risks to human health, while disease prevalence restricts the ability of livestock producers to meet international sanitary and phytosanitary standards.

2. DEVELOPMENTAL TRENDS IN ANIMAL AGRICULTURE

2.1 Intensification and Commercialization

There is an observable and increasingly significant structural transformation in livestock production systems in Nigeria and across West Africa, characterized by a gradual shift from predominantly extensive and subsistence-oriented systems toward more semi-intensive and intensive production models, particularly in the poultry and dairy subsectors. This transition is primarily driven by rapid urbanization, population growth, rising incomes, and changing consumer preferences for animal-source foods such as meat, milk, and eggs.

One of the major drivers of this shift is the expanding urban demand for animal protein. Urban centers such as Lagos, Abuja, Kano, Accra, and Dakar are experiencing sustained population growth, which has led to increased demand for safe, affordable, and readily available livestock products. This demand cannot be adequately met by traditional extensive systems, which are characterized by low productivity, seasonal output fluctuations, and weak market integration. Consequently, producers are increasingly adopting more controlled and production-oriented systems capable of delivering consistent supply to urban markets (Anaso, 2026a,b).

In response to these market pressures, the poultry sector has emerged as the most rapidly intensifying livestock subsector. Broiler and layer production systems are increasingly being organized under semi-intensive and intensive management conditions, where birds are housed in controlled environments, fed formulated rations, and managed under structured health and biosecurity protocols. These systems allow for faster turnover rates, higher feed conversion efficiency, and more predictable production cycles, making them more commercially viable and responsive to market demands.

Similarly, the dairy subsector is undergoing gradual intensification, particularly in peri-urban areas where demand for fresh milk and dairy products is high. Farmers are increasingly adopting improved dairy breeds or crossbreeds with higher milk yield potential and are shifting toward semi-confined systems that combine stall feeding with limited grazing. This allows for better control of nutrition, improved milk hygiene, and increased productivity per animal compared to traditional pastoral systems.

Another important factor driving intensification is the increasing commercialization and integration of livestock value chains. Private sector investment in feed milling, veterinary services, processing facilities, and cold chain infrastructure is expanding, particularly in poultry and dairy industries. This has improved access to inputs and markets, enabling producers to operate more efficiently within semi-intensive and intensive systems.

However, this transition is also associated with several structural constraints. Intensified systems are highly dependent on commercial feed resources, which are often expensive and subject to price volatility. Feed constitutes the largest proportion of production costs, particularly in poultry and dairy operations. As a result, profitability is highly sensitive to feed price fluctuations and supply chain disruptions.

In addition, intensive systems require higher levels of technical knowledge, capital investment, and biosecurity management, which may limit entry for smallholder farmers. Disease outbreaks in high-density production systems can spread rapidly if biosecurity measures are inadequate, leading to significant economic losses.

Despite these challenges, the trend toward intensification represents a critical pathway for improving productivity and meeting rising demand for animal-source foods in West Africa. It also provides opportunities for improved feed efficiency, better genetic utilization, and the integration of climate-smart practices such as precision feeding and emission reduction strategies.

2.2 Improved Breeding Programs

Efforts to introduce improved breeds and structured crossbreeding systems in Nigeria and across West Africa represent a key component of ongoing livestock sector transformation aimed at enhancing productivity, efficiency, and market competitiveness (Anaso et al., 2023). These interventions are particularly prominent in dairy cattle and poultry production systems, where genetic potential plays a decisive role in determining output levels such as milk yield, growth rate, feed conversion efficiency, and egg production.

In the dairy subsector, traditional indigenous cattle breeds—while highly adapted to harsh environmental conditions—exhibit relatively low milk yield potential. To address this limitation, there has been increasing interest in the introduction of exotic dairy breeds such as Holstein-Friesian, Jersey, and Brown Swiss, as well as their systematic crossbreeding with indigenous breeds like White Fulani (Bunaji) and Sokoto Gudali. The objective of these crossbreeding programs is to combine the high productivity traits of exotic breeds with the adaptive resilience of local breeds, particularly tolerance to heat stress, disease resistance, and ability to thrive under low-input systems (Anaso and Chibuogwu, 2026).

Crossbreeding initiatives are also being supported through government programs, research institutions, and private sector investments. Artificial insemination (AI) services are gradually expanding, although coverage remains limited and uneven across rural areas. Where successfully implemented, crossbreeding has demonstrated improvements in milk yield, growth performance, and reproductive efficiency. However, the sustainability of these gains is often constrained by inadequate feeding systems, poor veterinary support, and limited farmer capacity to manage high-performing animals.

In the poultry sector, genetic improvement has progressed more rapidly due to the shorter generation interval and higher commercialization level of the industry. Commercial poultry production in Nigeria is largely dependent on high-yield exotic strains of broilers, layers, and cockerels, which have been genetically selected for rapid growth, high feed conversion efficiency, and increased egg production. These strains are typically imported or supplied through multinational breeding companies, and they form the backbone of intensive poultry production systems.

Despite these advancements, the reliance on improved breeds and crossbreeding systems introduces several challenges.

Exotic breeds often require high-quality feed, optimal housing conditions, and strict health management protocols to express their full genetic potential. In environments where feed quality is poor or veterinary services are inadequate, the performance advantages of these breeds may not be fully realized, leading to suboptimal returns on investment.

Furthermore, indiscriminate crossbreeding without proper genetic planning can lead to genetic dilution of indigenous breeds, potentially eroding valuable adaptive traits that are essential for survival under harsh climatic and low-input conditions. This highlights the importance of structured breeding programs that balance productivity gains with the conservation of local genetic resources.

Another constraint is the limited infrastructure for genetic evaluation and breeding management, including lack of performance recording systems, weak extension services, and insufficient capacity for reproductive technologies such as AI, embryo transfer, and genomic selection. These limitations reduce the scalability and long-term impact of genetic improvement efforts.

Despite these challenges, the increasing focus on breed improvement and crossbreeding reflects a broader shift toward productivity-oriented livestock systems. When properly implemented within supportive feeding, health, and management frameworks, genetic improvement programs have the potential to significantly enhance livestock output, reduce production costs per unit, and improve food security outcomes in the region.

2.3 Climate-Smart Livestock Production

Climate change adaptation strategies are increasingly being integrated into livestock production systems across Nigeria and West Africa as part of a broader shift toward climate-smart agriculture, with a dual focus on enhancing system resilience and reducing greenhouse gas emissions. This integration is driven by the growing recognition that livestock systems are highly vulnerable to climate variability while simultaneously being significant contributors to global emissions, particularly methane (CH_4) from enteric fermentation.

A major pillar of these strategies is the reduction of greenhouse gas emissions, especially methane, through improved nutritional and management interventions.

Efforts include the optimization of animal diets to enhance digestibility and reduce fermentation losses, incorporation of feed additives such as phytogenic compounds, and increased utilization of agro-industrial by-products that improve rumen efficiency. These interventions are designed to shift rumen fermentation pathways toward greater propionate production and lower hydrogen availability, thereby reducing methanogenesis. In addition, improved manure management practices, such as composting, biogas production, and controlled storage systems, are being promoted to minimize methane and nitrous oxide emissions from waste decomposition.

Another key adaptation strategy is the improvement of feed efficiency, which directly influences both productivity and emission intensity. Feed-efficient animals produce more milk, meat, or eggs per unit of feed consumed, thereby reducing the overall environmental footprint of livestock production. This is being pursued through genetic improvement programs, precision nutrition systems, and better feed resource management. The integration of crop residues, improved forage species, and processed agro-industrial by-products into feeding systems helps bridge seasonal feed gaps and enhances nutrient availability. These strategies not only improve animal performance but also reduce reliance on environmentally costly feed crops.

Sustainable grazing management is also central to climate adaptation efforts, particularly in pastoral and agro-pastoral systems. Climate variability has led to increased degradation of rangelands, reduced pasture availability, and altered vegetation patterns. In response, initiatives such as rotational grazing, controlled stocking rates, pasture restoration, and establishment of grazing reserves are being promoted. These practices aim to prevent overgrazing, improve pasture regeneration, and enhance soil carbon sequestration. In some regions, fodder cultivation and rangeland rehabilitation programs are also being introduced to stabilize feed supply during dry seasons.

Additionally, climate adaptation strategies increasingly emphasize the integration of early warning systems and climate information services. Access to meteorological data allows livestock keepers to make informed decisions regarding migration, stocking rates, and feed management. Mobile-based advisory systems and digital extension services are gradually being introduced to improve dissemination of climate-related information to rural farmers.

Another important dimension is the enhancement of livestock resilience through diversification and system integration. Mixed crop–livestock systems are being strengthened to improve resource recycling and reduce vulnerability to climate shocks. Crop residues are increasingly being utilized as feed, while livestock manure is returned to crop fields as organic fertilizer, contributing to improved soil fertility and carbon cycling.

Despite these advancements, the adoption of climate change adaptation strategies remains uneven due to constraints such as limited technical capacity, inadequate funding, weak extension services, and low awareness among smallholder farmers. Nevertheless, ongoing policy reforms and international support frameworks, including those guided by the Intergovernmental Panel on Climate Change (IPCC), continue to drive progress toward more resilient and environmentally sustainable livestock systems.

2.4 Utilization of Agro-Industrial By-Products

The utilization of crop residues and agro-industrial by-products as alternative feed resources is increasingly gaining prominence in Nigeria and across West Africa as a strategic response to persistent challenges of feed scarcity, high feed costs, and low feed quality in livestock production systems. This trend reflects a broader shift toward resource-efficient and circular livestock production models, where agricultural wastes are revalorized into productive inputs for animal feeding rather than being discarded or underutilized.

Crop residues such as maize stover, rice straw, sorghum stalks, millet husks, and groundnut haulms are abundantly generated within mixed crop–livestock farming systems. Traditionally, these materials were considered low-value or waste products; however, their importance has increased significantly due to seasonal feed shortages, particularly during the dry season. Although inherently low in crude protein and digestibility, these residues provide a critical basal roughage source for ruminants and serve as the foundation of many smallholder feeding systems.

In parallel, agro-industrial by-products such as oilseed cakes (soybean cake, groundnut cake, palm kernel cake), brewery spent grains, maize offal, wheat bran, rice bran, and cassava peels are increasingly incorporated into livestock diets. These by-products are derived from food processing industries and are often available at relatively lower cost compared to conventional feed ingredients. Their nutritional composition varies, but many provide valuable sources of protein, energy, and essential minerals that complement fibrous crop residues in balanced rations.

The growing use of these alternative feed resources is driven by several interrelated factors. First, the rising cost and competition for conventional feed ingredients such as maize and soybean have made traditional concentrates economically unsustainable for many producers, particularly smallholders. Second, rapid expansion of agro-processing industries has increased the availability of by-products, creating new opportunities for livestock feed formulation. Third, increasing awareness of sustainable agriculture and waste reduction has encouraged the integration of circular economy principles into livestock production systems (Anaso and Anaso, 2025).

From a nutritional standpoint, the combination of crop residues and agro-industrial by-products allows for dietary balancing, where energy-rich and protein-rich components are used to complement fibrous basal feeds. This improves rumen fermentation efficiency, enhances microbial protein synthesis, and increases overall feed conversion efficiency. In ruminant systems, such dietary strategies can also influence volatile fatty acid profiles and reduce methane emission intensity by improving digestibility and altering fermentation pathways.

Despite these advantages, the utilization of these feed resources is constrained by several limitations. Crop residues are often characterized by high lignocellulosic content, low palatability, and poor digestibility unless subjected to treatment methods such as urea ammoniation, ensiling, or microbial processing. Agro-industrial by-products, on the other hand, may contain anti-nutritional factors (cyanogenic compounds in cassava peels) or exhibit variability in nutrient composition depending on processing methods. Additionally, inadequate storage facilities and seasonal fluctuations in availability can limit consistent supply.

Nevertheless, the increasing integration of crop residues and agro-industrial by-products into livestock feeding systems represents a significant advancement toward sustainable and climate-smart livestock production. It not only reduces feed costs and environmental waste but also contributes to improved resource efficiency and reduced pressure on arable land used for feed crop cultivation. In the long term, strengthening value chains for these materials through better processing, quality standardization, and feed formulation technologies will be critical for maximizing their contribution to livestock productivity and environmental sustainability.

Digital Transformation

Emerging technologies such as mobile livestock platforms, AI-based disease prediction, and digital extension services are gradually improving efficiency and decision-making.

Policy Reforms and Investments

Government initiatives and livestock transformation programs in Nigeria and across West Africa represent structured policy responses designed to address long-standing inefficiencies in animal agriculture, particularly low productivity, weak animal health systems, poor market integration, and inadequate value addition. These interventions are increasingly framed within broader national development agendas that emphasize food security, import substitution, rural development, and climate-smart agriculture.

A central objective of these programs is the enhancement of livestock productivity through systemic modernization. This includes efforts to improve access to superior genetic resources, promote artificial insemination services, strengthen breeding programs, and support the adoption of improved management practices. Governments are increasingly recognizing that productivity gains cannot be achieved solely through herd expansion, but rather through intensification, efficiency improvements, and better resource utilization per animal.

Another critical focus area is the strengthening of veterinary services and animal health systems.

Livestock transformation programs often include investments in veterinary infrastructure, such as the rehabilitation of veterinary clinics, expansion of disease surveillance systems, and improvement of vaccine production and distribution networks. These initiatives aim to reduce the burden of endemic and transboundary animal diseases, improve outbreak response capacity, and enhance overall herd health. In addition, regulatory frameworks are being strengthened to control antimicrobial use and promote responsible drug administration in livestock systems, thereby addressing concerns related to antimicrobial resistance.

Government policies also increasingly target livestock value chain development, recognizing that inefficiencies are not limited to production alone but extend across processing, distribution, and marketing systems. Value chain interventions include the development of slaughter facilities, cold chain infrastructure, milk collection centers, feed processing industries, and livestock markets. These investments are intended to reduce post-harvest losses, improve product quality and safety, and enhance market access for producers, particularly smallholder farmers.

In addition, many livestock transformation programs emphasize the integration of smallholder farmers into formal and commercial markets. This is achieved through cooperative formation, capacity building, access to credit facilities, and linkage to input and output markets. By organizing producers into cooperatives or clusters, governments aim to improve economies of scale, enhance bargaining power, and facilitate access to extension services and modern technologies.

There is also increasing policy attention on pasture development and feed resource management, including the establishment of grazing reserves, fodder banks, and rangeland rehabilitation projects. These initiatives are designed to address chronic feed shortages, reduce resource-use conflicts, and improve livestock nutrition. In some cases, programs also promote the cultivation of improved forages and the utilization of agro-industrial by-products as part of sustainable feeding strategies.

Furthermore, livestock transformation programs are being aligned with climate change adaptation and mitigation goals.

This includes promoting climate-smart livestock practices such as improved feed efficiency, methane reduction strategies, waste-to-energy systems, and sustainable land management. These initiatives reflect a growing recognition of the environmental footprint of livestock systems and the need to balance productivity with ecological sustainability.

Despite these efforts, implementation challenges remain significant. Issues such as inadequate funding, weak institutional coordination, limited extension coverage, policy inconsistency, and governance constraints often reduce the effectiveness of these programs. In some cases, infrastructure projects are not fully operationalized, and benefits do not adequately reach smallholder producers who constitute the majority of livestock farmers.

Emerging Challenges

Farmer–herder conflicts, climate variability, and land-use pressures constitute some of the most significant structural constraints undermining livestock production systems in Nigeria and across West Africa. These interconnected challenges operate at environmental, socio-economic, and governance levels, collectively disrupting production stability, reducing productivity, and limiting the sustainable expansion of the livestock sector.

Farmer–herder conflicts have become increasingly frequent and severe in recent decades, particularly in the savannah and derived savannah zones of Nigeria. These conflicts arise primarily from competition over access to land, water resources, and grazing routes between crop farmers and pastoral livestock keepers. As agricultural expansion intensifies and human populations increase, traditional grazing corridors and pasturelands are progressively encroached upon by crop cultivation and urban development. This spatial overlap leads to frequent resource-use clashes, livestock destruction of farmlands, retaliatory violence, and displacement of pastoral communities.

The consequences of these conflicts extend beyond immediate loss of life and property. They disrupt livestock mobility patterns, particularly in transhumant pastoral systems that depend on seasonal migration. Restricted movement reduces access to quality pasture and water, leading to poor animal nutrition, weight loss, reduced reproductive performance, and increased susceptibility to diseases.

In many cases, herders are forced into more confined grazing systems or displacement zones where feed resources are insufficient, further exacerbating production inefficiencies.

Climate variability is another critical driver of livestock production instability. West Africa is highly vulnerable to climate change impacts, including erratic rainfall patterns, prolonged dry seasons, increasing temperatures, and recurrent drought events. These changes directly affect pasture growth, water availability, and feed crop productivity. As a result, livestock systems that depend heavily on natural grazing are particularly exposed to seasonal feed deficits and environmental stress (Anaso, 2024).

Rising temperatures also contribute to heat stress in livestock, which negatively affects feed intake, growth rate, milk yield, fertility, and immune function. In addition, climate-induced changes in vegetation patterns alter the distribution and nutritional quality of forage species, often leading to a decline in available biomass quality. This further intensifies feed scarcity and increases reliance on low-quality crop residues, thereby reducing production efficiency and increasing methane emission intensity.

Land-use pressures further compound these challenges by altering the spatial availability of grazing resources. Rapid population growth, urban expansion, industrial development, and agricultural intensification have led to widespread conversion of grazing lands into farmlands and settlements. This reduction in available grazing space limits herd mobility and reduces the carrying capacity of traditional rangelands. In many areas, communal grazing systems are being replaced by privatized or restricted land tenure systems, which further constrains pastoral access to resources.

The combined effect of these pressures is a progressive fragmentation of traditional livestock production systems, forcing a transition from extensive pastoralism toward more sedentary and semi-intensive systems. While this transition may offer opportunities for improved management and commercialization, it also places additional burdens on feed supply systems, veterinary services, and infrastructure, which are often underdeveloped.

Moreover, these disruptions have broader socio-economic implications, including reduced livestock productivity, increased production costs, food insecurity, and heightened vulnerability of rural livelihoods.

They also contribute to migration pressures, social instability, and reduced investment in livestock enterprises due to insecurity and uncertainty.

Constraints To Livestock Development

- Feed scarcity and low-quality diets
- Weak veterinary infrastructure
- Climate change and environmental degradation
- Limited access to finance and credit
- Poor extension services
- Inadequate policy implementation
- Conflict over land and water resources

Future Prospects

Future livestock development in West Africa is expected to be shaped by:

- Climate-smart livestock systems
- Precision nutrition and digital livestock management
- Improved genetic selection and breeding technologies
- Expansion of feed processing industries
- Circular bioeconomy approaches
- Stronger public–private partnerships

CONCLUSION

Animal agriculture in West Africa, particularly in Nigeria, is at a critical transition point between traditional subsistence systems and modern, technology-driven production systems. While current practices remain largely extensive and constrained by structural inefficiencies, emerging trends indicate increasing adoption of intensification, innovation, and sustainability-oriented approaches. Addressing persistent constraints such as feed shortages, weak institutional systems, and climate-related pressures will be essential for achieving a productive, resilient, and sustainable livestock sector in the region.

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