Journals Pub

International Journal of
Animal Biotechnology and Applications

ISSN: 2455-7315
Volume 11, Issue 1, 2025
January—June
DOI (Journal): 10.37628/IJABA

https://journalspub.com/journal/ijaba

Review IJABA

Integrating Trees, Shrubs, and Perennial Biomass Crops into Livestock Systems: A Pathway to Sustainable Tropical Farming Systems

Md. Emran Hossain[1,*], Shilpi Islam[2]

Abstract

Livestock production in the tropics faces increasing challenges due to climate change, land degradation, feed shortages, and environmental concerns. Integrating trees, shrubs, and perennial biomass crops into livestock farming systems offers a sustainable approach to addressing these challenges. This study explores the potentials of agroforestry-based livestock systems in enhancing feed availability, improving animal nutrition, promoting soil health, and mitigating the environmental footprint of livestock farming. Trees and shrubs provide high-protein forage, improve microclimatic conditions, and contribute to soil fertility through nitrogen fixation and organic matter enrichment. Perennial biomass crops, such as sugarcane, cassava, and sweet potato offer a consistent and energy-rich feed supply while optimizing land use efficiency. Silvopastoral systems facilitate nutrient cycling, reduce greenhouse gas emissions, and enhance biodiversity conservation. Additionally, integrating perennial vegetation reduces reliance on conventional feed resources, stabilizes fodder production across seasons, and fosters climate resilience. This review synthesizes evidence on the benefits and challenges of tree–livestock integration, highlighting species selection, management strategies, and economic viability. A transition toward tree-based livestock systems could improve productivity while ensuring ecological balance and long-term sustainability. Further research is needed to refine management practices and quantify the long-term impacts of integrating trees, shrubs, and perennial crops into tropical livestock farming systems.

Keywords: Agroforestry, climate resilience, feed security, livestock sustainability, perennial crops, silvopastoral systems, tropical farming

INTRODUCTION

Livestock farming in the tropics plays a critical role in food security, rural livelihoods, and economic development. However, conventional livestock production systems face increasing challenges, including land degradation, deforestation, feed shortages, and climate variability [1]. Rising demand for livestock products further exacerbates pressure on natural resources, necessitating the adoption of sustainable practices. Integrating trees, shrubs, and perennial biomass crops into livestock systems presents an alternative approach that enhances feed security, improves ecosystem services, and promotes long-term agricultural sustainability [2]. Agroforestry and silvopastoral systems, which combine woody perennials with pasture and livestock, have been recognized for their potential to optimize land use while mitigating environmental degradation [3]. By

***Author for Correspondence**
Md. Emran Hossain
E-mail: emran@cvasu.ac.bd

[1]Professor, Department of Animal Science and Nutrition, Chattogram Veterinary and Animal Sciences, University, Khulshi, Chattogram, Bangladesh
[2]Professor, Department of Animal Science and Nutrition, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh

Received Date: February 26, 2025
Accepted Date: February 27, 2025
Published Date: March 06, 2025

Citation: Md. Emran Hossain, Shilpi Islam. Integrating Trees, Shrubs, and Perennial Biomass Crops into Livestock Systems: A Pathway to Sustainable Tropical Farming Systems. International Journal of Animal Biotechnology and Applications. 2025; 11(1): 11–28p.

© JournalsPub 2025. All Rights Reserved

leveraging the diverse benefits of these integrated systems, tropical livestock farming can transition toward greater resilience and efficiency.

Trees and shrubs contribute to livestock nutrition by providing protein-rich fodder, reducing seasonal feed shortages, and improving rumen health through secondary metabolites [4]. Additionally, they enhance soil fertility through nitrogen fixation, organic matter accumulation, and improved water retention. Perennial biomass crops, such as sugarcane, cassava, and sweet potato offer a consistent energy supply, minimizing dependence on expensive and volatile feed resources. These systems also create microclimatic benefits, offering shade and reducing heat stress in animals, which is particularly crucial in tropical environments. Furthermore, integrating deep-rooted perennial vegetation promotes carbon sequestration, enhances biodiversity, and reduces greenhouse gas emissions associated with conventional livestock farming [5]. Despite these advantages, successful implementation requires strategic selection of plant species, proper management practices, and a thorough understanding of economic feasibility.

This study presents a comprehensive review of integrating trees, shrubs, and perennial biomass crops into tropical livestock systems, emphasizing their potential to enhance productivity and sustainability. Unlike previous studies that focus on either agroforestry or silvopastoral systems in isolation, this review adopts a holistic perspective by examining the synergistic role of woody perennials and high-biomass crops in livestock nutrition, environmental conservation, and climate adaptation. The study synthesizes recent advancements in plant-livestock interactions, explores practical implementation strategies, and highlights key knowledge gaps. By addressing both the opportunities and challenges associated with tree-based livestock systems, this study provides a framework for sustainable livestock production in the tropics, contributing to long-term agricultural resilience and food security.

FORAGE AND FEED RESOURCES

Protein-Rich Tree Leaves

Leaves from trees and shrubs serve as an excellent protein source for livestock, improving growth and milk production [6]. Their high digestibility and amino acid profile make them a sustainable alternative to conventional protein feeds. Additionally, they offer a year-round feed supply, reducing seasonal feed shortages and stabilizing livestock nutrition in tropical systems.

Sugarcane Tops as Basal Diet

Sugarcane tops, often discarded in sugar processing, provide a cost-effective basal diet for ruminants. Their fiber content supports rumen function, while their energy-rich composition complements protein sources [7]. Supplementing sugarcane tops with nitrogen-rich feeds can enhance digestibility, making them an efficient alternative to traditional roughages in tropical livestock production systems.

Cassava Foliage and Roots

Cassava plants contribute both foliage and roots, supplying carbohydrates and protein essential for livestock growth and maintenance. The leaves, rich in protein, can be used as a forage supplement, while the roots offer a dense energy source. Proper processing reduces anti-nutritional factors, allowing cassava to serve as a sustainable and locally available feed resource.

Sweet Potato Vines for Fiber

Sweet potato vines are a valuable source of highly digestible fiber, supporting gut health and improving feed efficiency. Their rapid regrowth allows multiple harvests, ensuring a consistent supply. The vines also contain vitamins and minerals that contribute to overall livestock health, making them an important component of sustainable tropical livestock systems [8].

Leguminous Trees for Nitrogen Fixation

Leguminous trees, such as *Leucaena* and *Gliricidia* enhance forage quality by naturally fixing nitrogen, enriching the soil, and improving pasture productivity. Their leaves provide high-protein

© JournalsPub 2025. All Rights Reserved

fodder, reducing reliance on conventional protein sources [9]. The presence of bioactive compounds can further improve rumen fermentation, promoting efficient digestion and enhancing animal performance.

Energy-Rich Tree Pods

Tree pods from species, such as Prosopis and Acacia provide an excellent energy source for livestock, particularly in arid and semi-arid regions. Their carbohydrate-rich composition enhances dietary energy intake, supporting growth and lactation. The natural tannins in some pods can also have anthelmintic properties, reducing parasite loads in grazing animals.

Shrub Foliage for Dry-Season Feeding

Shrub foliage serves as a vital supplement during dry seasons when conventional forages become scarce. Species, such as Calliandra and Sesbania maintain their leaf biomass year-round, providing a steady protein supply [10]. Their resilience to drought ensures continuous feed availability, making them essential for stabilizing livestock productivity in fluctuating climatic conditions.

High-Biomass Crops for Silage

High-biomass crops, such as Napier grass and hybrid forages produce large amounts of fodder suitable for silage and haymaking [11]. Their rapid growth and high yield potential support consistent feed availability, reducing dependence on external feed sources. Proper ensiling techniques enhance their nutritional value, providing high-energy and fiber-rich feed throughout the year.

Multi-Purpose Trees as Feed Sources

Multi-purpose trees supply various livestock feed components, including leaves, bark, fruits, and flowers. Species, such as Moringa and Ficus offer nutritional diversity, enhancing dietary balance [12]. These trees also contribute to ecosystem stability by preventing soil erosion and improving microclimatic conditions, further supporting sustainable livestock production in tropical regions.

Secondary Metabolites for Gut Health

Bioactive compounds in trees and shrubs positively influence gut health, digestion, and immunity. Phytochemicals, such as tannins and saponins can regulate microbial populations in the digestive tract, improving nutrient absorption and reducing methane emissions [13]. Their natural antimicrobial properties also help lower the incidence of enteric infections, promoting overall livestock well-being and productivity.

SUSTAINABLE FEED PRODUCTION

Extended Fodder Growing Season

Trees and shrubs extend the availability of fresh forage beyond traditional pasture cycles. Their ability to retain foliage during dry periods ensures continuous feed supply, reducing seasonal shortages [14]. This extended growth period stabilizes livestock productivity, minimizing dependence on external feed sources and enhancing overall system resilience in tropical regions.

Deep-Rooted Species for Moisture Access

Species with deep root systems extract nutrients and moisture from deeper soil layers, allowing them to remain productive in drought conditions. These plants support forage availability during dry seasons, maintaining livestock nutrition without requiring irrigation. Their ability to stabilize soil structure further contributes to long-term agricultural sustainability.

Shade-Tolerant Crops in Agroforestry

Shade-tolerant crops maximize land use efficiency by thriving under tree canopies in agroforestry systems. This integration increases overall forage yield per unit area, promoting sustainable intensification [15]. By utilizing vertical space, agroforestry systems optimize land productivity without

© JournalsPub 2025. All Rights Reserved

compromising livestock feed availability.

Coppicing Shrubs for Continuous Regrowth

Coppicing shrubs, when properly managed, regenerate quickly after harvesting, ensuring a continuous supply of fresh fodder. Their ability to withstand repeated cutting extends their lifespan and maximizes biomass production. This regrowth mechanism reduces the need for frequent replanting, supporting long-term feed sustainability.

Multi-Purpose Trees for Resilience

Multi-purpose trees contribute to system resilience by offering diverse benefits beyond fodder production, including soil enrichment, climate regulation, and habitat provision [16]. Their multifunctionality strengthens the overall stability of livestock production, reducing vulnerability to climate variability and environmental degradation.

Minimal External Inputs Needed

Tree and shrub-based feeding systems require fewer external inputs, such as fertilizers and irrigation compared to conventional fodder crops. Their natural adaptability reduces reliance on synthetic inputs, lowering production costs while enhancing sustainability. This low-input approach supports resource-efficient livestock farming.

Year-Round Feed Availability

Agroforestry systems enhance year-round feed availability by integrating plant species with staggered growth and harvesting cycles. This approach ensures a continuous supply of fresh, high-quality forage, preventing seasonal feed gaps and stabilizing livestock productivity in the tropics [17].

Dual-Purpose Cassava and Sweet Potato

Cassava and sweet potato serve both human and livestock needs, maximizing resource utilization. While roots provide human nutrition, their foliage and vines offer valuable livestock feed [18]. This dual-purpose use enhances food security while optimizing land productivity, making these crops integral to sustainable tropical farming.

Rotational Leaf Harvesting Prevents Deforestation

Sustainable harvesting practices, such as rotational leaf cutting, prevent excessive deforestation while maintaining tree health. This method ensures a long-term supply of high-quality fodder without degrading natural forests [19]. Proper management balances feed extraction with ecological conservation, supporting sustainable land use.

Perennial Plants for Feed Security

Perennial plants provide a stable forage base by reducing seasonal feed fluctuations. Their long lifespan and deep-root systems contribute to consistent biomass production, ensuring livestock have access to reliable nutrition throughout the year. Their resilience to environmental stressors strengthens overall feed security in tropical livestock systems.

CLIMATE RESILIENCE AND ADAPTATION

Heat Stress Mitigation for Livestock

Trees and shrubs provide natural shade, reducing ambient temperatures in grazing areas and minimizing heat stress in livestock. This cooler microclimate improves feed intake, growth performance, and reproductive efficiency [20]. By mitigating thermal stress, tree-based systems enhance animal welfare and productivity in tropical livestock farming.

Drought-Resistant Species for Feed Security

Drought-resistant trees and shrubs remain productive even in arid conditions, ensuring continuous feed supply during dry periods. Their ability to thrive with minimal water input stabilizes livestock

© JournalsPub 2025. All Rights Reserved

nutrition, reducing dependence on external feed sources and promoting resilience in water-scarce environments.

Buffering Against Extreme Weather

Agroforestry systems act as natural windbreaks and buffers, reducing the impact of extreme weather events, such as storms, heavy rainfall, and prolonged droughts. By stabilizing soil and moderating microclimatic conditions, these systems help maintain consistent forage production and livestock performance.

Erosion Control Through Soil Cover

High-biomass crops protect soil from erosion by maintaining ground cover and improving organic matter content. Their extensive root systems anchor the soil, preventing nutrient loss and degradation [21]. This contributes to long-term soil fertility, supporting sustainable livestock production.

Silvopastoral Productivity Under Climate Change

Silvopastoral systems integrate trees with livestock grazing, maintaining productivity in the face of climate change [22]. By improving soil structure, conserving moisture, and providing year-round forage, these systems enhance adaptive capacity while sustaining both animal performance and ecosystem health.

Deep-Rooted Trees Accessing Groundwater

Trees with deep root systems tap into groundwater reserves, ensuring green biomass availability during droughts [23]. This natural water access reduces reliance on surface irrigation and provides livestock with a continuous source of forage, even in prolonged dry conditions.

Microclimate Regulation for Livestock Comfort

Trees help regulate microclimates by reducing temperature fluctuations and increasing humidity in grazing areas. This moderates heat stress, improving livestock well-being and feed efficiency. By creating favourable environmental conditions, trees contribute to better health and performance in tropical livestock systems.

Sustainable Tree Pruning for Forage Supply

Regular, controlled pruning of fodder trees ensures continuous forage availability without compromising tree health [24]. Proper management allows trees to regenerate, maintaining a steady supply of high-protein leaves while preserving ecosystem functions and long-term feed sustainability.

Seasonal Feed Synchronization

Deciduous trees shed leaves in sync with seasonal cycles, providing a natural feed source when other forages are scarce. This predictable pattern enhances livestock diet planning, reducing seasonal nutritional deficiencies and optimizing feeding strategies in tropical systems.

Climate-Smart Tree Species for Adaptation

Selecting climate-resilient tree species ensures long-term adaptability to shifting weather patterns. Drought-tolerant, fast-growing, and nutrient-efficient trees enhance sustainability by providing consistent forage, improving carbon sequestration, and supporting ecosystem resilience in livestock farming.

SOIL HEALTH AND NUTRIENT CYCLING

Nitrogen Fixation by Leguminous Trees

Leguminous trees, such as *Leucaena* and *Gliricidia*, naturally fix nitrogen, enriching soil fertility and reducing the need for chemical fertilizers. Their ability to improve nitrogen levels in the soil enhances overall forage quality and promotes healthy pasture growth [25]. This natural fertilization process supports sustainable farming practices, reducing input costs and environmental impact.

© JournalsPub 2025. All Rights Reserved

Nutrient Cycling by Deep-Rooted Plants

Deep-rooted plants access nutrients from subsoil layers, bringing them to the surface for other plants to utilize. This nutrient cycling process improves overall soil fertility, reducing the need for synthetic fertilizers [26]. These plants also contribute to soil structure, increasing nutrient availability and promoting a more balanced ecosystem.

Improvement of Soil Quality by Leaf Litter

Leaf litter from trees and shrubs enhances soil quality by adding organic matter, which increases microbial activity and improves soil structure [27]. As this organic material decomposes, it enriches the soil with essential nutrients, improving water retention and supporting healthier, more productive forage growth.

Agroforestry Systems Reduce Nutrient Leaching

Agroforestry systems, with their diverse plant species and deep-rooted trees, reduce nutrient leaching by stabilizing the soil and preventing water runoff [21]. The root systems of trees help hold nutrients in place, ensuring they remain available for plant uptake. This minimizes soil erosion and maintains soil health in the long term.

Tree Roots Prevent Soil Compaction

Tree roots help break up compacted soil, improving water infiltration and root penetration for other plants [28]. This enhanced soil structure promotes better drainage, prevents waterlogging, and encourages healthier plant growth. By reducing compaction, trees foster a more resilient soil environment, benefiting both trees and livestock.

Livestock Manure Boosts Tree and Shrub Growth

Livestock manure, when applied under trees and shrubs, provides essential nutrients that support plant growth. The organic matter from manure enriches the soil with nitrogen, phosphorus, and other key elements, encouraging healthy vegetation [29]. Manure also contributes to improved soil texture and structure, benefiting both forage production and tree growth.

Rotational Grazing Under Trees

Rotational grazing under trees helps distribute livestock excreta more evenly, promoting balanced nutrient cycling. This practice prevents overgrazing in one area, enhances soil fertility, and ensures that nutrients are replenished across the grazing area [30]. It also reduces the risk of soil degradation while encouraging healthy pasture regeneration.

Nutrient Recycling in Silvopastoral Systems

Silvopastoral systems integrate trees and livestock, creating a natural nutrient recycling cycle [31]. Tree roots, livestock manure, and fallen leaves combine to create a fertile environment, boosting soil nutrient levels. These systems optimize the use of available resources, reducing dependency on external inputs and contributing to sustainable farming practices.

Soil Stabilization on Sloped Lands

Shrubs, particularly those with extensive root systems, play a crucial role in preventing soil degradation on sloped lands. Their roots bind the soil, reducing erosion caused by rainfall and wind [32]. This enhances soil stability, prevents nutrient loss, and supports the long-term productivity of both trees and livestock in hilly areas.

Decomposition Acceleration by Livestock Excreta

Livestock excreta under tree systems accelerates the decomposition of organic matter, enriching the soil with nutrients. The presence of manure stimulates microbial activity, which breaks down plant material more rapidly, enhancing soil fertility [33]. This process supports healthier, faster-growing vegetation and a more sustainable farming system.

© JournalsPub 2025. All Rights Reserved

BIODIVERSITY AND ECOLOGICAL SERVICES

Habitat for Beneficial Insects and Birds

Trees and shrubs create diverse habitats for beneficial insects, such as pollinators and natural pest predators, as well as for birds that help control pests [34]. These ecosystems enhance biodiversity, improve pollination rates, and contribute to natural pest control, reducing the need for chemical pesticides. By fostering wildlife, these systems support healthier livestock farming environments.

Increased Biodiversity in Mixed-Species Systems

Integrating a variety of tree, shrub, and plant species in livestock systems promotes greater biodiversity, which enhances ecosystem stability. Mixed-species systems support a wide range of wildlife, improve resilience to environmental changes, and offer ecological benefits, such as pest control and soil fertility enhancement, making farming systems more sustainable.

Pollinator-Friendly Tree Species

Pollinator-friendly tree species, such as flowering trees, provide essential resources for pollinators like bees and butterflies. These species increase pollination rates for both crops and forage plants, ensuring a stable food supply for livestock [35]. By supporting pollinators, these trees enhance ecosystem services and contribute to the long-term productivity of livestock systems.

Perennial Crops and Microbial Diversity

Perennial crops, such as tree legumes and other multi-purpose species, support diverse soil microbial communities by maintaining a stable root system year-round. These plants promote nutrient cycling, improve soil health, and sustain a balanced microbial ecosystem, which enhances the productivity and sustainability of both forage and livestock systems.

Reduction of Synthetic Fertilizer Use

Agroforestry systems with trees and shrubs reduce the need for synthetic fertilizers by enhancing natural nutrient cycling. The biological processes in these systems, such as nitrogen fixation and organic matter decomposition, provide essential nutrients for plants [36]. This reduces the environmental impact of fertilizer use and supports more sustainable farming practices.

Pest-Repelling Tree Species

Certain tree species, such as neem and moringa, have natural pest-repelling properties that can reduce the need for chemical pesticides in livestock farming [37]. These trees help protect both livestock and crops from pests, improving livestock health and contributing to more sustainable, organic farming practices.

Prevention of Land Degradation by Shrubs

Shrubs, especially those with dense root systems, prevent land degradation by stabilizing the soil and reducing erosion [38]. Their ability to improve soil structure and fertility makes them essential for maintaining healthy grazing lands. This promotes long-term sustainability and resilience in tropical livestock systems, even in areas prone to soil erosion.

Reduced Vulnerability to Pests and Diseases

Mixed-crop systems, which incorporate a variety of plants, reduce the vulnerability of livestock farming to pests and diseases [39]. By diversifying plant species, these systems create a more complex ecosystem that can disrupt pest cycles, improve plant health, and reduce the need for chemical pest management strategies.

Fostering Ecosystem Resilience Through Fodder Trees

Integrating fodder trees into livestock systems helps build ecosystem resilience by providing a diverse range of products, such as leaves, fruits, and pods [40]. These trees support the food chain by enhancing soil fertility, conserving water, and improving biodiversity, contributing to the long-term sustainability

© JournalsPub 2025. All Rights Reserved

of farming systems in the tropics.

Carbon Sequestration by Trees

Trees play a critical role in offsetting greenhouse gas emissions from livestock production through carbon sequestration [41]. As trees absorb CO_2 from the atmosphere and store it in their biomass and soil, they mitigate climate change and enhance the sustainability of livestock systems, making them an important component of carbon management strategies.

ECONOMIC BENEFITS AND COST REDUCTION

Reduction in Feed Costs with Homegrown Tree Fodder

Homegrown tree fodder significantly reduces feed costs by providing a readily available, low-cost source of nutrition for livestock. Trees and shrubs, like Leucaena and Gliricidia, offer high-protein leaves, reducing dependence on expensive commercial feed, thus lowering overall feed expenditure and improving farm profitability [42].

Long-Term Economic Benefits from Perennial Plants

Perennial plants, such as trees and shrubs, offer long-term economic returns by providing consistent, renewable resources over multiple seasons. These plants require fewer inputs once established, and their ability to regenerate annually reduces the need for replanting, making them a cost-effective choice for sustainable farming systems.

Sustainable Biomass Harvesting Reduces Feed Dependency

By harvesting biomass from trees and shrubs, farmers can sustainably reduce their reliance on commercial feeds. This biomass, which includes leaves, pods, and branches, provides a stable, renewable feed source, thereby lowering feed costs and minimizing the environmental impact associated with industrial feed production.

Dual-Purpose Crops for Increased Farm Income

Dual-purpose crops, such as cassava and sweet potato, offer both food and feed value, enhancing farm income by diversifying the products sold. These crops provide essential nutrients for livestock and serve as valuable food crops for human consumption, ensuring that farms benefit from multiple revenue streams.

Reduction in Reliance on Imported Protein Sources

Tree-based feeds, such as the leaves of leguminous trees, reduce the need for importing protein-rich feed ingredients like soybean meal [43]. By utilizing locally grown tree fodder, farms can lower their feed-related expenses and promote food security by reducing dependency on external sources.

Enhanced Farm Productivity Through Livestock and Tree Integration

The integration of livestock and trees, as seen in silvopastoral systems, enhances farm productivity by diversifying production and improving resource use efficiency [44]. Trees provide forage, shade, and additional products, such as fruits or timber, while livestock contribute manure, which improves soil health, leading to better crop and livestock yields.

Diversification of Farm Income Through Tree Fodder Sales

Selling tree fodder, such as leaves or branches, as a feed resource provides an additional income stream for farmers [45]. This diversification reduces the financial risks associated with farming and creates a more resilient farm economy, where multiple products can be marketed simultaneously.

Increased Land-Use Efficiency Through Agroforestry Systems

Agroforestry systems, which combine trees, shrubs, and livestock on the same land, maximize land-use efficiency by utilizing different vertical layers and spatial niches [46]. This approach optimizes

© JournalsPub 2025. All Rights Reserved

production while minimizing land area required for diverse farming activities, increasing overall farm output without the need for expansion.

Improved Profitability with Reduced Feed Purchase Costs

By utilizing tree-based feeds and homegrown fodder, farmers can significantly reduce the costs of purchasing commercial feed. This cost reduction directly improves profitability by lowering operational expenses while maintaining livestock health and productivity.

Lower Fertilizer Expenses with Manure Application

The application of livestock manure in agroforestry systems reduces the need for chemical fertilizers by recycling nutrients within the system [47]. Manure enriches soil fertility, promoting better plant growth, while also reducing external input costs, which lowers overall farm production expenses and contributes to cost-effective and sustainable farming.

LIVESTOCK HEALTH AND WELFARE

Improvement in Rumen Fermentation by Phytochemicals

Phytochemicals found in tree leaves, such as tannins and saponins, positively influence rumen fermentation by promoting the growth of beneficial microbes while inhibiting harmful pathogens [48]. This leads to improved feed utilization, better digestion, and enhanced overall animal health. By integrating tree fodder, farmers can optimize rumen function, which supports more efficient livestock production.

Enhancement of Animal Health Through Medicinal Tree Species

Certain tree species, such as moringa and neem, contain medicinal properties that can improve livestock health by providing natural remedies for various ailments [49]. These trees offer bioactive compounds that can help prevent diseases, enhance recovery from infections, and maintain general well-being, reducing the need for pharmaceutical treatments and improving animal welfare.

Reduction of Heat Stress with Shade Trees

Shade trees play a crucial role in mitigating heat stress in grazing animals, particularly in tropical regions. The canopy provided by these trees offers shelter from intense sunlight, lowering the body temperature of livestock [50]. This leads to reduced stress, improved feed intake, and enhanced productivity, contributing to better overall health and welfare for the animals.

Reduction of Parasite Burdens with Natural Tannins

Natural tannins present in the leaves of trees, such as Leucaena and Mimosa act as anthelmintics, reducing parasite burdens in grazing animals [51]. These tannins help to control gastrointestinal parasites, improving overall livestock health by reducing the need for chemical dewormers, thus contributing to a more sustainable and cost-effective livestock management system.

Boosting Immunity with Tree-Derived Bioactive Compounds

Bioactive compounds in tree foliage, including antioxidants and antimicrobial agents, have been shown to enhance the immune system of livestock [52]. Regular consumption of such tree-based feeds can help boost resistance to diseases, improve recovery rates from infections, and promote better overall health, reducing veterinary costs and increasing productivity.

Support for Rumen Health with High-Fiber Tree Fodder

High-fiber tree fodder, such as the leaves of browse species, supports rumen health by promoting proper digestion and regular motility [53]. The fiber content helps maintain the integrity of the rumen lining and supports the growth of beneficial microbes, which is vital for nutrient absorption and overall digestive health in ruminants.

© JournalsPub 2025. All Rights Reserved

Promotion of Gut Microbiota Balance with Shrub-Based Fodder

Shrub-based fodder, rich in both fiber and secondary metabolites, promotes a balanced gut microbiota in livestock. These plants help in maintaining a healthy gut environment by supporting the growth of beneficial bacteria and suppressing harmful microorganisms. This balance plays a significant role in improving digestion, nutrient absorption, and overall health.

Reduction in Metabolic Disorders with Fodder Trees

Fodder trees, particularly those with high mineral content, can reduce the incidence of metabolic disorders, such as bloat or acidosis in ruminants. These trees provide essential nutrients, like calcium, magnesium, and phosphorus, that contribute to proper metabolic function, ensuring the health of livestock while enhancing productivity.

Provision of Essential Minerals with Multi-Purpose Trees

Multi-purpose trees, such as moringa and mulberry, provide livestock with essential minerals, including calcium, magnesium, and trace elements. These minerals are vital for various physiological functions, such as bone health, immune response, and reproductive efficiency. Ensuring a balanced mineral intake supports long-term animal health and optimal performance.

Reduction of Nutritional Deficiencies Through Diverse Forage Sources

Feeding a diverse range of forage sources, including tree leaves, shrubs, and high-biomass crops, reduces the risk of nutritional deficiencies in livestock [54]. This diverse diet ensures a more balanced intake of proteins, carbohydrates, vitamins, and minerals, leading to improved overall health, better performance, and reduced reliance on supplements or commercial feeds.

EFFICIENT LAND USE AND RESOURCE OPTIMIZATION

Silvopastoral Systems for Coexistence of Livestock and Trees

Silvopastoral systems allow livestock and trees to coexist harmoniously, optimizing land use by utilizing both vertical and horizontal space [55]. This integration provides multiple benefits, including forage production, shade for livestock, and additional tree-based products, such as fruits or timber, leading to improved productivity per unit area while enhancing farm resilience.

Maximization of Output with High-Biomass Crops

High-biomass crops, such as sugarcane and cassava, maximize land productivity by producing large amounts of fodder and food in a small area. These crops help increase farm output without requiring additional land, ensuring that both food and feed production are optimized, which is especially beneficial in land-scarce tropical regions.

Reduction of Land Competition with Fodder Trees

Fodder trees reduce the competition for land between food and feed crops by providing additional feed resources on the same piece of land. This allows farmers to cultivate both food crops for human consumption and trees for livestock forage without the need for separate plots, thus optimizing overall land use.

Enhancement of Tree Regrowth Through Rotational Browsing

Rotational browsing, where livestock are moved between different grazing areas, helps enhance the regrowth of trees [56]. By preventing overgrazing and allowing periods of rest for trees, this practice ensures that tree-based fodder remains available for livestock throughout the year, while maintaining long-term sustainability of the system.

Integration of High-Value Crops in Alley Cropping

Alley cropping integrates high-value crops, such as fruits or vegetables, with livestock production in between rows of trees. This system allows for the efficient use of land by producing high-value crops alongside fodder, maximizing overall farm output and ensuring diversified income sources without

© JournalsPub 2025. All Rights Reserved

requiring additional land space [57].

Optimization of Land Use Under Tree Canopies

Pasture under tree canopies optimizes land utilization by providing grazing areas for livestock while benefiting from the shade and shelter offered by trees [50]. This combination reduces heat stress on animals and increases pasture productivity, ensuring that land is used efficiently throughout the year.

Stratified Feed Production with Multi-Tiered Tree Systems

Multi-tiered tree systems, where trees of varying heights are planted, allow for stratified feed production. This system optimizes land use by utilizing different levels of the space for growing feed, fruits, and timber, thus improving farm productivity while preserving biodiversity and ecosystem health.

Nitrogen Fixation by Tree Legumes Supporting Intercrops

Tree legumes, such as Leucaena and Gliricidia, play a crucial role in supporting intercrops by fixing nitrogen in the soil [58]. This reduces the need for chemical fertilizers and enhances soil fertility, making it easier to grow both tree-based fodder and food crops efficiently in the same system.

Enhanced Farm Sustainability with Intensive Tree-Livestock Systems

Intensive tree-livestock systems optimize the land by incorporating high-density planting of trees alongside livestock grazing. These systems ensure sustainable production by increasing resource efficiency, reducing external inputs, and maintaining ecological balance, which leads to long-term farm sustainability and resilience to climate changes.

Agroforestry for Optimized Land use in Livestock and Crop Production

Agroforestry systems combine livestock and crop production on the same land, optimizing resource use and land productivity [59]. These systems integrate trees, crops, and livestock to maximize output from a given area, reducing competition and promoting a more sustainable, efficient agricultural model that benefits both food security and farm profitability.

WATER CONSERVATION AND MANAGEMENT

Tree Cover Reduces Evaporation and Retains Soil Moisture

Tree cover helps reduce evaporation rates by providing shade and cooling the soil. This shade creates a microclimate that minimizes direct sunlight exposure, which helps retain soil moisture [60]. In turn, it reduces the need for frequent irrigation and enhances soil fertility, supporting sustainable livestock farming in the tropics.

Deep-Rooted Plants Improve Water Infiltration

Deep-rooted plants, such as trees, access water from deeper soil layers and improve water infiltration. These roots create pathways in the soil, enhancing its structure and allowing rainwater to penetrate more effectively [61]. This increases soil moisture retention and ensures a more reliable water supply for both crops and livestock.

Perennial Crops Minimize Runoff and Soil Erosion

Perennial crops, such as cassava and sweet potato, provide continuous ground cover that helps reduce runoff and prevent soil erosion [62]. Their extensive root systems hold soil together, protecting it from water erosion during heavy rains and ensuring that water is absorbed more effectively, benefiting both crop and livestock production.

Water-Efficient Species Enhance Dryland Livestock Farming

Water-efficient tree and crop species, such as moringa and cacti, are particularly beneficial in dryland livestock farming. These species require less water to thrive, making them ideal for arid and semi-arid regions where water resources are limited [63]. Their incorporation into livestock systems can help sustain productivity even during dry spells.

© JournalsPub 2025. All Rights Reserved

Tree-Based Systems Reduce Reliance on Irrigation

Tree-based systems, such as agroforestry, help reduce the need for irrigation by improving soil moisture retention and reducing water loss. The presence of trees helps in maintaining more consistent soil moisture levels, allowing for less frequent irrigation and reducing overall water consumption in livestock farming systems [64].

Mulching From Tree Litter Conserves Moisture in Pastures

Tree litter, including fallen leaves and bark, acts as mulch, conserving moisture in pastures by reducing evaporation from the soil [65]. This mulch layer also helps suppress weeds, maintain soil temperature, and enrich soil organic matter, further enhancing pasture productivity and reducing the need for supplemental irrigation.

Tree Roots Stabilize Water Channels, Preventing Degradation

Tree roots play a critical role in stabilizing water channels, preventing erosion, and maintaining the integrity of waterways. By reinforcing riverbanks and preventing soil degradation, tree-based systems contribute to better water management, ensuring that clean water remains available for livestock and crops even in regions with fluctuating water levels [66].

Agroforestry Systems Improve Watershed Health

Agroforestry systems enhance watershed health by promoting the filtration and retention of water [21]. Trees and shrubs improve water quality by preventing nutrient runoff into nearby water sources and contribute to the regulation of water flow, which benefits both aquatic ecosystems and the livestock that rely on these waters.

Trees act as Windbreaks, Reducing Moisture Loss From Soil

Trees, especially those planted as windbreaks, protect soil moisture by reducing the drying effects of wind [67]. Windbreaks create a barrier that minimizes the exposure of soil to drying winds, preserving the moisture content in the soil. This helps maintain a stable environment for both livestock grazing and crop growth.

High-Biomass Plants Contribute to Green Water Recycling

High-biomass plants, such as sugarcane and forage grasses, contribute to green water recycling by absorbing rainwater during wet periods and slowly releasing it during dry spells. This helps maintain a steady water supply for livestock, reduces water stress on the system, and ensures efficient water use throughout the year.

WASTE MANAGEMENT AND CIRCULAR ECONOMY

Agroforestry Reduces Waste Through Integrated Nutrient Cycling

Agroforestry systems foster integrated nutrient cycling, where organic matter, such as fallen leaves, tree litter, and livestock manure is recycled back into the soil [68]. This reduces waste and enriches soil fertility, closing the loop within the system and reducing the need for external chemical inputs while promoting sustainable farming practices.

Cassava Peels Serve as an Energy-Rich Livestock Feed

Cassava peels, typically a byproduct of human consumption, serve as an energy-rich feed for livestock [69]. By repurposing these agricultural residues, farmers can reduce waste and provide an affordable and nutritious feed alternative, making use of what would otherwise be discarded and promoting a more circular agricultural economy.

Sugarcane Bagasse Is Repurposed as Livestock Feed

Sugarcane bagasse, the fibrous residue left after extracting juice from sugarcane, is repurposed as livestock feed [70]. This biomass can be utilized as a roughage source for ruminants, offering an eco-

© JournalsPub 2025. All Rights Reserved

friendly option for feed while also minimizing waste in sugarcane farming, contributing to a more sustainable, circular farming system.

Tree Pruning Residues Become Valuable Livestock Feed

Tree pruning residues, such as branches and leaves, can be turned into valuable livestock feed. These pruned materials, often discarded as waste, offer a sustainable and cost-effective feed resource for livestock, reducing waste and contributing to the efficient use of tree-based systems in livestock production.

Shrubs Provide Biomass for Composting, Enriching Soil Fertility

Shrubs in agroforestry systems contribute biomass that can be used for composting. The decomposed plant matter enriches soil fertility, enhancing nutrient cycling and reducing the need for synthetic fertilizers. This practice promotes sustainable land management and minimizes agricultural waste by converting plant residues into valuable organic matter.

Agroforestry Allows Efficient Use of Manure as a Soil Amendment

In agroforestry systems, livestock manure is efficiently utilized as a soil amendment. Manure can be applied to trees, shrubs, and crops, providing essential nutrients and closing nutrient loops [71]. This practice minimizes waste, reduces dependency on external fertilizers, and enhances soil health, contributing to a circular agricultural economy.

High-Biomass Crop Residues Reduce Feed Wastage

High-biomass crops, such as cassava and sweet potato, produce large amounts of residues that can be used to supplement livestock feed. These residues, when properly harvested and processed, can reduce feed wastage, providing livestock with additional nutrients and ensuring that no valuable biomass goes unused, thereby promoting a circular and sustainable farming system.

Silage Made from Tree Leaves Extends Feed Storage

Tree leaves, such as those from Leucaena or Gliricidia, can be used to produce silage, extending feed storage. By preserving tree foliage as silage, farmers can ensure a stable and nutritious feed supply during lean periods, reducing reliance on external feed inputs and minimizing waste associated with seasonal feed shortages.

Sweet Potato Vines Serve as Both Fresh Feed and Silage Material

Sweet potato vines, a byproduct of tuber harvesting, serve as both fresh feed and silage material for livestock [72]. These vines are rich in fiber and nutrients, and by preserving them as silage, farmers can reduce waste while providing livestock with high-quality forage throughout the year, making use of the entire plant and promoting a circular economy.

Integrated Systems Reduce Dependency on Synthetic Feed Inputs

Integrated farming systems that incorporate trees, shrubs, and high-biomass crops reduce dependency on synthetic feed inputs [73]. By utilizing plant residues, agroforestry products, and manure, these systems recycle nutrients and organic matter, decreasing the need for commercially produced feeds and contributing to more sustainable, circular farming practices.

CONCLUSIONS

Integrating trees, shrubs, and perennial biomass crops into tropical livestock farming systems presents a viable strategy for enhancing productivity, sustainability, and climate resilience. These systems improve feed availability, enhance animal nutrition, and contribute to soil health while mitigating the environmental footprint of livestock farming. The combination of deep-rooted perennials and nitrogen-fixing species supports carbon sequestration, biodiversity conservation, and long-term agricultural sustainability. However, successful implementation requires appropriate species selection, efficient management practices, and economic feasibility assessments. This study highlights the

© JournalsPub 2025. All Rights Reserved

potential of tree-based livestock systems and underscores the need for further research on optimizing plant-livestock interactions. Adopting these integrated approaches can transform tropical livestock farming into a more resilient and resource-efficient system, ensuring long-term food security and ecological balance.

Future Directions

Future research should focus on optimizing species selection based on regional climate, soil conditions, and livestock dietary requirements. Long-term studies are needed to assess the economic viability of integrating trees, shrubs, and perennial biomass crops into livestock farming and their impact on productivity. Investigating the role of secondary metabolites in improving rumen efficiency and disease resistance can enhance feed formulations. Advancements in agroforestry-based precision farming techniques, including remote sensing and machine learning, could improve resource management and system optimization. Further exploration of carbon sequestration potential in tree-integrated livestock systems will provide insights into mitigating greenhouse gas emissions. Additionally, policy frameworks must be developed to support farmers in adopting silvopastoral and agroforestry practices through incentives and extension services. Strengthening interdisciplinary research collaborations will facilitate knowledge exchange, ensuring that integrated livestock production systems contribute to long-term sustainability, climate adaptation, and global food security in tropical regions.

REFERENCES

1. Thornton PK, Herrero M. The inter-linkages between rapid growth in livestock production , climate change, and the impacts on water resources, land use, and deforestation. World Dev. 2010; (January): 84.
2. Notenbaert AMO, Douxchamps S. Tapping into the environmental co-benefits of improved tropical forages for an agroecological transformation of livestock production systems. 2021. Available from: http://doi.org/10.3389/fsufs.2021.742842
3. Moreno G, Rolo V. Agroforestry practices: Silvopastoralism. Agroforestry for sustainable agriculture, Burleigh Dodds Science Publishing; 2019:119–164.
4. Chriyaa A. The use of shrubs in livestock feeding in low rainfall areas. L Use, L Cover Soil Sci V Dry Lands Desertif. 2009:73.
5. George SJ, Harper RJ, Hobbs RJ, Tibbett M. A sustainable agricultural landscape for Australia: A review of interlacing carbon sequestration, biodiversity and salinity management in agroforestry systems. Agric Ecosyst Environ. 2012;163:28–36. http://doi.org/10.1016/j.agee.2012.06.022
6. Devendra C. Use of shrubs and tree fodders by ruminants. Shrubs and tree fodders for farm animals: Proceedings of a workshop in Denpasar, Indonesia, 24-29 July 1989, IDRC, Ottawa, ON, CA, 1990.
7. Pate FM, Alvarez J, Phillips JD, Eiland BR. Sugarcane as a cattle feed: Production and utilization. Bulletin 2002;844:1–21.
8. Megersa T, Urge M, Nurfeta A. Effects of feeding sweet potato (Ipomoea batatas) vines as a supplement on feed intake, growth performance, digestibility and carcass characteristics of Sidama goats fed a basal diet of natural grass hay. Trop Anim Health Prod. 2013;45:593–601.
9. Domínguez-Núñez JA. Leguminous trees for sustainable tropical agroforestry. Adv Legum Sustain Intensif. 2022:483–504. Available from: http://doi.org/10.1016/B978-0-323-85797-0.00006-9
10. Hove L, Topps JH, Sibanda S, Ndlovu LR. Nutrient intake and utilisation by goats fed dried leaves of the shrub legumes Acacia angustissima, Calliandra calothyrsus and Leucaena leucocephala as supplements to native pasture hay. Anim Feed Sci Technol. 2001;91(1–2):95–106.
11. Islam MR, Garcia SC, Sarker NR, Islam MA, Clark CEF. Napier grass (Pennisetum purpureum Schum) management strategies for dairy and meat production in the tropics and subtropics: yield and nutritive value. Front Plant Sci. 2023;14: 1269976. Available from: http://doi.org/10.3389/fpls.2023.1269976
12. Preston TR. The role of multi-purpose trees in integrated farming systems for the wet tropics. FAO Anim Prod Heal Pap, 1992;(102):193–209.

© JournalsPub 2025. All Rights Reserved

13. Lambo MT, Ma H, Liu R, Dai B, Zhang Y, Li Y. Review: Mechanism, effectiveness, and the prospects of medicinal plants and their bioactive compounds in lowering ruminants' enteric methane emission. Animal, 2024: 101134. Available from: https://doi.org/10.1016/j.animal.2024.101134
14. Ben Salem H, Smith T. Feeding strategies to increase small ruminant production in dry environments. Small Rumin Res. 2008;77(2–3):174–194. Available from: https://doi.org/10.1016/j.smallrumres.2008.03.008
15. Muschler RG. Agroforestry: Essential for sustainable and climate-smart land use?. 2016. Available from: https://doi.org/10.1007/978-3-642-54601-3_300
16. A. Keprate, Bhardwaj DR, Sharma P, Verma K, Abbas G, Sharma V, et al. Climate resilient agroforestry systems for sustainable land use and livelihood. World Sustainability Series 2024: 141–161. Available from: https://doi.org/10.1007/978-3-031-63430-7_7
17. Vinodhini SM, Manibharathi S, Pavithra G, Sakthivel S. Agroforestry: Integrating trees into agricultural systems. Delhi, India: Elite Publishing house; 2023.
18. Peters D. Assessment of the potential of sweet potato as livestock feed in East Africa : Rwanda , Uganda , and Kenya A report presented to The International Potato Center (CIP) in Nairobi. A Rep Present to Int Potato Cent Nairobi 2008;64(July):1–64.
19. Cooper PJM, Leakey RRB, Rao MR, Reynolds L. Agroforestry and the mitigation of land degradation in the humid and sub-humid tropics of Africa. … Agric. 1996 [Online]. Available from: https://www.cambridge.org/core/journals/experimental-agriculture/article/agroforestry-and-the-mitigation-of-land-degradation-in-the-humid-and-subhumid-tropics-of-africa/EF33E02F9F6690DBFFFD4F641C09BF5B
20. Masters D, Blache D, Lockwood AL, Maloney S, Norman H, Refshauge G, et al. Shelter and shade for grazing sheep: Implications for animal welfare and production and for landscape health. Anim Prod Sci. 2023;63(7):623–644. Available from: https://doi.org/10.1071/AN22225
21. X. Zhu, Wenjie L, Jin C, Adrian BL, Zhun M, Xiaodong Y, et al. Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: A review of evidence and processes. Plant and Soil 2020;453(1–2). Available from: https://doi.org/10.1007/s11104-019-04377-3
22. Dagar JC, Gupta SR. Silvopasture options for enhanced biological productivity of degraded pasture/grazing lands: an overview. Agrofor Degrad Landscapes Recent Adv Emerg Challenges 2020;2:163–227.
23. Kühnhammer K, van Haren J, Kübert A, Bailey K, Dubbert M, Hu J, et al. Deep roots mitigate drought impacts on tropical trees despite limited quantitative contribution to transpiration. Sci Total Environ. 2023;893: 164763. Available from: https://doi.org/10.1016/j.scitotenv.2023.164763
24. Raj AK, Raj RM, Kunhamu TK, Jamaludheen V, Chichaghare AR. Management of tree fodder banks for quality forage production and carbon sequestration in humid tropical cropping systems – An overview. Indian J Anim Sci. 2023;93(1):10–22. Available from: https://doi.org/10.56093/ijans.v93i1.120692.
25. Jayasundara HPS, Dennett MD, Sangakkara UR. Biological nitrogen fixation in Gliricidia septum and Leucaena leucocephala and transfer of fixed nitrogen to an associated grass. Trop Grasslands, 1998;31(6):529–537.
26. Thorup-Kristensen K, Halberg N, Nicolaisen M, Olesen JE, Crews TE, Hinsinger P. Digging deeper for agricultural resources, the value of deep rooting. Trends Plant Sci. 2020;25(4):406–417.
27. Song Y, Yu Y, Li Y, Du M. Leaf litter chemistry and its effects on soil microorganisms in different ages of Zanthoxylum planispinum var. Dintanensis. BMC Plant Biol. 2023;23(1):262. Available from: https://doi.org/10.1186/s12870-023-04274-z
28. Bartens J, Day SD, Harris JR, Dove JE, Wynn TM. Can urban tree roots improve infiltration through compacted subsoils for stormwater management?. J Environ Qual. 2008;37(6):2048–2057. Available from: https://doi.org/10.2134/jeq2008.0117
29. Rayne N, Aula L. Livestock manure and the impacts on soil health: A review. Soil Syst. 2020;4(4):1–26. Available from: https://doi.org/10.3390/soilsystems4040064
30. Teague R, Kreuter U. Managing grazing to restore soil health, ecosystem function, and ecosystem

© JournalsPub 2025. All Rights Reserved

services. Front Sustain Food Syst. 2020;4:534187. Available from: https://doi.org/10.3389/fsufs.2020.534187
31. Sarabia L, Solorio FJ, Ramírez L, Ayala A, Aguilar C, Ku J, et al. Improving the nitrogen cycling in livestock systems through silvopastoral systems. Nutr Dyn Sustain Crop Prod. 2020:189–213.
32. Cao T, Zhang H, Chen T, Yang C, Wang J, Guo Z, et al. Research on the mechanism of plant root protection for soil slope stability. PLoS One, 2023;18(11):e0293661.
33. Bhunia S, Bhowmik A, Mallick R, Mukherjee J. Agronomic efficiency of animal-derived organic fertilizers and their effects on biology and fertility of soil: A review. Agronomy, 2021;11(5):823. Available from: https://doi.org/10.3390/agronomy11050823
34. Nicholls CI, Altieri MA. Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. Agron Sustain Dev. 2013;33:257–274.
35. Bożek B, Denisow B, Strzałkowska-Abramek M, Chrzanowska E, Winiarczyk K. Non-forest woody vegetation: A critical resource for pollinators in agricultural landscapes—a review. Sustainability. 2023;15(11):8751.
36. Nair PKR. Agroforestry systems and environmental quality: Introduction. J Environ Qual, 2011;40(3):784–790.
37. Iso Nta A, Etta Agbo B, Francis Etim I, Bassey DA, Imalele EE. Bioinsecticidal activities of azadirachta indica and moringa oleifera against maize weevil (Sitophilus Zeamais) and rice weevil (sitophilus oryzae) – a review. Glob J Pure Appl Sci. 2024;30(3):271–282. Available from: https://doi.org/10.4314/gjpas.v30i3.1
38. Zhang C, Wang Y, Jia X, An Z. Impacts of shrub introduction on soil properties and implications for dryland revegetation. Sci Total Environ. 2020;742:140498.
39. Thornton PK, Herrero M. Climate change adaptation in mixed crop–livestock systems in developing countries. Glob Food Sec. 2014;3(2):99–107.
40. Kumar RV, Gautam K, Ghosh A, Singh AK, Kumar S. Silvopasture systems for round-the-year fodder production and building ecological resilience on degraded landscapes. Agroforestry Solutions for Climate Change and Environmental Restoration 2024:415–436. Available from: https://doi.org/10.1007/978-981-97-5004-7_19
41. Reyes-Palomo C, Aguilera E, Llorente M, Díaz-Gaona C, Moreno G, Rodríguez-Estévez V. Carbon sequestration offsets a large share of GHG emissions in dehesa cattle production. J Clean Prod. 2022;358:131918. Available from: https://doi.org/10.1016/j.jclepro.2022.131918
42. Raj AK, Kunhamu TK, Jamaludheen V, Chichaghare AR. Upscaling fodder tree integration in humid tropical agroforestry systems–Prospects and constraints. Indian J Agrofor. 2022;24(3).
43. Halmemies-Beauchet-Filleau A, Rinne M, Lamminen M, Mapato C, Ampapon T, Wanapat M, et al. Alternative and novel feeds for ruminants: Nutritive value, product quality and environmental aspects. Animal, 2018;12(s2):s295–s309.
44. Vandermeulen S, Ramírez-Restrepo CA, Beckers Y, Claessens H, Bindelle J. Agroforestry for ruminants: A review of trees and shrubs as fodder in silvopastoral temperate and tropical production systems. Anim Prod Sci, 2018;58(5):767–777.
45. Chakeredza S, Hove L, Akinnifesi FK, Franzel S, Ajayi OC, Sileshi G. Managing fodder trees as a solution to human–livestock food conflicts and their contribution to income generation for smallholder farmers in southern Africa. Natural Resources Forum, 2007:286–296.
46. Keerthika A, Lakshmi P, Chavan SB, Subbu Lakshmi V, Choudhary KK, Noor Mohamed MB, et al.. Multistrata agroforestry systems: Spatial and temporal utilization of resources for higher production and better income. Agroforestry Solutions for Climate Change and Environmental Restoration. 2024:33–61.
47. Alex S, Arruda M, Barros LB, Ferraz-Almeida R, Deyvid D, Carvalho Maranhão DD, et al. Chemical attributes of the soil in agroforestry systems subjected to organic fertilizations," African J Agric Res. 2016;11(27):2378–2388.
48. Patra AK, Saxena J. Dietary phytochemicals as rumen modifiers: A review of the effects on microbial populations. Antonie van Leeuwenhoek, Int J Gen Mol Microbiol. 2009;96(4):363–375. https://doi.org/10.1007/s10482-009-9364-1

© JournalsPub 2025. All Rights Reserved

49. Du Preez DA, Akanmu AM, Adejoro FA, Hassen A. The effect of monensin vs. neem, and moringa extracts on nutrient digestibility, growth performance, methane, and blood profile of merino lambs. Animals, 2023;13(22):3514.
50. Ainsworth JAW, Moe SR, Skarpe C. Pasture shade and farm management effects on cow productivity in the tropics. Agric Ecosyst Environ. 2012; 155: 105–110 . Available from: https://doi.org/10.1016/j.agee.2012.04.005
51. Ramdani D, Yuniarti E, Jayanegara A, Chaudhry AS. Roles of essential oils, polyphenols, and saponins of medicinal plants as natural additives and anthelmintics in ruminant diets: A systematic review. Animals, 2023;13(4):767.
52. Provenza FD, Villalba JJ. The role of natural plant products in modulating the immune system: An adaptable approach for combating disease in grazing animals. Small Rumin Res. 2010;89(2–3):131–139.
53. Devendra C. Nutritional potential of fodder trees and shrubs as protein sources in ruminant nutrition. Legum trees other Fodd trees as protein sources Livest. 1992;100:95–113.
54. Hazra CR. Feed and forage resources for sustainable livestock development. Range Manag Agrofor. 2014;35(1):1–14.
55. Poudel S, Pent G, Fike J. Silvopastures: Benefits, past efforts, challenges, and future prospects in the United States. Agronomy, 2024;14(7):1369.
56. R. Smith et al. "Rotational grazing," Univ. Kentucky Coll Agric. 2011.
57. Xu H, Bi H, Gao L, Yun L. Alley cropping increases land use efficiency and economic profitability across the combination cultivation period. Agronomy. 2019;9(1):34.
58. Jayasundara HPS, Dennett MD, Sangakkara UR. Biological nitrogen fixation in gliricidia sepium and leucaena leucocephala and transfer of fixed nitrogen to an associated grass. Trop grasslands. 1997;31:529–537.
59. Kang BT, Akinnifesi FK. Agroforestry as alternative land-use production systems for the tropics. Nat Resour Forum. 2000. Available from: https://doi.org/10.1111/j.1477-8947.2000.tb00938.x
60. Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, et al. Trees, forests and water: Cool insights for a hot world. Glob Environ Chang. 2017;43:51–61. Available from: https://doi.org/10.1016/j.gloenvcha.2017.01.002
61. Bodner G, Mentler A, Keiblinger K. Plant roots for sustainable soil structure management in cropping systems. Root Syst Sustain Agric Intensif. 2021:45–90. Available from: https://doi.org/10.1002/9781119525417.ch3
62. Wei Z, Huang J, Yang X, Fu H. To uplift the profitability of marginal lands by cassava cultivation. Agric Sci. 2024;15(11):1163–1178.
63. K. P. Devkota, Devkota M, Mabhaudhi T, Nangia V, Attaher S, Boroto RJ, et al. A blueprint for building resilience and food security in MENA and SSA drylands: Diversifying agriculture with neglected and underutilized species. Food Energy Secur. 2025;14(1):e70046.
64. D. Siriri, Wilson J, Coe R, Tenywa MM, Bekunda MA, Ong CK, et al. Trees improve water storage and reduce soil evaporation in agroforestry systems on bench terraces in SW Uganda. Agrofor Syst. 2013;87(1):45–58. Available from: https://doi.org/10.1007/s10457-012-9520-x
65. R. Iqbal, Sammar Raza MA, Valipour M, Farrukh Saleem M, Saqlain Zaheer M, Ahmad S, et al. Potential agricultural and environmental benefits of mulches—a review. Bull Natl Res Cent. 2020;44:1–16.
66. Gyssels G, Poesen J, Bochet E, Li Y. Impact of plant roots on the resistance of soils to erosion by water: a review. Prog Phys Geogr. 2005;29(2):189–217.
67. Mume ID, Workalemahu S. Review on windbreaks agroforestry as a climate smart agriculture practices. Am J Agric For. 2021;9(6):342–347.
68. Sileshi GW, Mafongoya PL, Nath AJ. Agroforestry systems for improving nutrient recycling and soil fertility on degraded lands. Agrofor. Degrad. Landscapes Recent Adv. Emerg. Challenges-2020;1:225–253. Available from: https://doi.org/10.1007/978-981-15-4136-0_8
69. Manju MW, Wadhwa, Bakshi MPS, Makkar HPS. Waste to worth: Fruit wastes and by-products as animal feed. CABI Rev. 2015;2015:1–26.

© *JournalsPub 2025. All Rights Reserved*

70. Harrison MD. Sugarcane-derived animal feed. Sugarcane-based biofuels Bioprod. 2016:281–310.
71. Mohamed Nikzaad R, Nusrathali N. Integrating livestock and crop systems for enhanced productivity and grassland conservation in developing countries. In Grasslands-Conservation and Development, IntechOpen. 2024. Available from: https://doi.org/10.5772/intechopen.113109
72. Tsegaye T, Mekasha Y, Bayssa M. Effects of inclusion levels of sweet potato vine silage in the concentrate mixture on feed intake, milk yield and composition of crossbred dairy cows fed natural pasture hay. Livest Res Rural Dev. 2024;36(4):4.
73. Roggero PP, Bellon S, and Rosales M. Sustainable feeding systems based on the use of local resources. In Annales de zootechnie; 1996. p. 105–118.

© *JournalsPub 2025. All Rights Reserved*