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ANALYSIS OF CARRYING CAPACITY AND LAND SUITABILITY FOR THE DEVELOPMENT OF CATTLE-BASED AGROSILVOPASTORAL SYSTEMS IN TALUDITI SUBDISTRICT: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Agro-silvopastoral systems integrate trees, forage/crops, and livestock within the same land unit and are increasingly framed as a pathway to reconcile production objectives with ecosystem restoration in rural landscapes. Yet the evidence base remains dispersed across disciplines and contexts, making it difficult to translate research into practical design, carrying-capacity decisions, and spatial targeting for cattle development programs. This systematic literature review synthesises peer-reviewed empirical studies on agro-silvopastoral systems and closely related agroforestry-livestock configurations, with attention to (i) typologies and design choices, (ii) environmental performance and ecosystem services, (iii) livelihood and economic outcomes, and (iv) governance and scaling mechanisms. The review followed established systematic review guidance and a transparent screening, appraisal, and extraction protocol (Liberati et al., 2009; Moher et al., 2015; Tricco et al., 2018). Across the literature, outcomes are consistently context-dependent and mediated by management intensity, land tenure and labour constraints, market access, and institutional support. Environmental benefits (soil protection, carbon storage, microclimate regulation, and biodiversity habitat) are most evident where tree and ground-cover components are maintained, stocking rates align with forage availability, and nutrient cycling is actively managed (Jose & Dollinger, 2019; Torralba et al., 2016). Livelihood effects are strongest when systems diversify income streams and reduce seasonal risk, but equity and benefit distribution depend on who controls land, labour, and decision-making (Giusti et al., 2019). The synthesis highlights an integrated planning implication: land suitability and carrying capacity should be treated as social-ecological design questions rather than purely biophysical calculations, and should be paired with participatory governance to support adoption and long-term performance.
Keywords: agro-silvopastoral systems, agroforestry, carrying capacity, land suitability.

ABSTRAK

Sistem agro-silvopastoral mengintegrasikan pohon, hijauan/tanaman, dan ternak dalam satu unit lahan yang sama dan semakin dipandang sebagai jalur untuk menyelaraskan tujuan produksi dengan restorasi ekosistem di lanskap pedesaan. Namun, basis bukti masih tersebar di berbagai disiplin ilmu dan konteks, sehingga sulit untuk menerjemahkan penelitian ke dalam desain praktis, keputusan daya dukung, dan penargetan spasial untuk program pengembangan ternak. Tinjauan literatur sistematis ini mensintesis studi empiris yang ditinjau sejawat tentang sistem agro-silvopastoral dan konfigurasi agroforestri-peternakan yang terkait erat, dengan memperhatikan (i) tipologi dan pilihan desain, (ii) kinerja lingkungan dan jasa ekosistem, (iii) mata pencaharian dan hasil ekonomi, dan (iv) tata kelola dan mekanisme penskalaan. Tinjauan ini mengikuti panduan tinjauan sistematis yang telah ditetapkan dan protokol penyaringan, penilaian, dan ekstraksi yang transparan (Liberati et al., 2009; Moher et al., 2015; Tricco et al., 2018). Dalam literatur, hasil secara konsisten bergantung pada konteks dan dimediasi oleh intensitas pengelolaan, kepemilikan lahan dan kendala tenaga kerja, akses pasar, dan dukungan kelembagaan. Manfaat lingkungan (perlindungan tanah, penyimpanan karbon, pengaturan iklim mikro, dan habitat keanekaragaman hayati) paling terlihat di mana komponen pohon dan penutup tanah

dipertahankan, tingkat penggembalaan selaras dengan ketersediaan pakan, dan siklus nutrisi dikelola secara aktif (Jose & Dollinger, 2019; Torralba et al., 2016). Efek mata pencaharian paling kuat ketika sistem mendiversifikasi aliran pendapatan dan mengurangi risiko musiman, tetapi kesetaraan dan distribusi manfaat bergantung pada siapa yang mengendalikan lahan, tenaga kerja, dan pengambilan keputusan (Giusti et al., 2019). Sintesis ini menyoroti implikasi perencanaan terpadu: kesesuaian lahan dan daya dukung harus diperlakukan sebagai pertanyaan desain sosial-ekologis daripada perhitungan biofisik semata, dan harus dipasangkan dengan tata kelola partisipatif untuk mendukung adopsi dan kinerja jangka panjang.
Kata kunci: sistem agro-silvopastoral, agroforestri, daya dukung, kesesuaian lahan.

INTRODUCTION

Agro-silvopastoral systems (ASPS) refer to land-use configurations that intentionally combine woody perennials with herbaceous vegetation and livestock, sometimes alongside annual crops. In practice, this umbrella includes silvopasture, parkland and scattered-tree grazing, tree-crop-livestock mosaics, and homegarden-livestock complexes. The conceptual foundation is shared with broader agroforestry, but the presence of livestock introduces additional feedbacks through grazing pressure, manure and nutrient cycling, and competition (or complementarity) among trees, ground cover, and animals (Nair, 1989, 1993, 2012). Agroforestry has also been framed as a pathway to advance food security and poverty reduction while sustaining ecosystem services (Garrity, 2004).

Interest in ASPS has risen as governments and development agencies seek ‘triple-win’ strategies: maintaining or improving rural incomes, supporting climate mitigation and adaptation, and reducing land degradation. Evidence across regions suggests that tree integration can enhance soil structure and infiltration, reduce erosion and heat stress, diversify products, and support landscape heterogeneity that benefits biodiversity (Altieri, 2004; Jose & Dollinger, 2019; Torralba et al., 2016). At the same time, reported outcomes vary widely. Some systems underperform economically or generate unintended ecological trade-offs when tree density, species selection, grazing management, or institutional conditions are mismatched with local contexts (Malek & Verburg, 2017; Shrestha et al., 2018). In Indonesia, recent national statistical series provide an essential empirical baseline for estimating livestock supply, feed demand, and regional development targets that inform carrying capacity and land-use planning (Badan Pusat Statistik, 2019, 2024; Ministry of Agriculture of the Republic of Indonesia, 2023).

For cattle development planning-particularly in frontier or forest-margin areas-two operational questions recur. First, where are ASPS interventions most suitable, given slope, soils, rainfall, access, and competing land uses? Second, what stocking levels and management regimes maintain carrying capacity without degrading vegetation and soils? These questions cannot be answered by biophysical indicators alone. Adoption and sustained performance depend on tenure security, labour availability, knowledge and extension services, and the governance arrangements that coordinate farmers, agencies, and markets (Scherr & McNeely, 2008; Pretty, 2003).

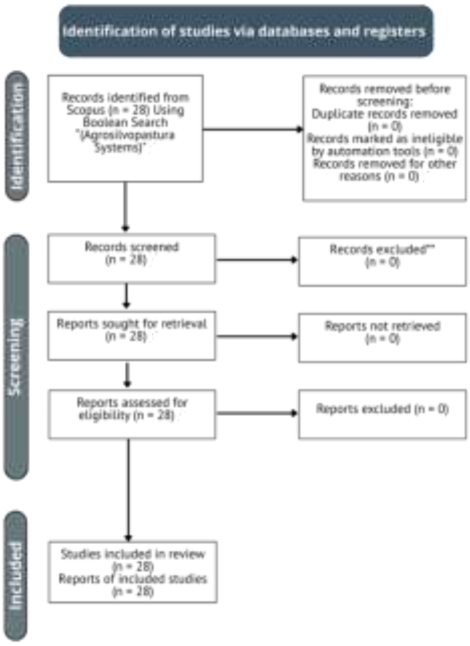
Although many primary studies examine components of ASPS, the evidence remains fragmented across agronomy, ecology, economics, and governance literatures. This review therefore synthesises empirical findings to support more coherent design and policy choices. Specifically, it asks: (1) How are ASPS typologised and what design drivers are reported? (2) What environmental outcomes and indicators are most commonly assessed, and under what conditions are benefits realised? (3) What livelihood and economic effects are observed, including issues of equity? and (4) What governance and participation mechanisms enable adoption and scaling?

METHODS

This review followed systematic review principles and transparent reporting guidance commonly used in environmental and social-ecological research (Liberati et al., 2009; Moher et al., 2015; Tricco et al., 2018). A structured search string combining terms related to agroforestry, silvopasture, tree-livestock integration, ecosystem services, and livelihoods was applied to bibliographic databases and complemented by targeted backward and forward citation checks for influential conceptual sources. Eligibility criteria prioritised peer-reviewed empirical studies that: (i) examined land-use systems explicitly integrating woody perennials with livestock; (ii) reported biophysical and/or socio-economic outcomes; and (iii) provided sufficient methodological detail to support appraisal. Studies focusing solely on conventional pasture without tree components, purely conceptual commentaries, and non-empirical notes were excluded.

Screening was conducted in stages (title/abstract, then full-text), with decisions recorded against the inclusion criteria. Quality appraisal relied on established checklists suited to mixed-method environmental evidence, assessing clarity of research questions, appropriateness of design, transparency of measurement, and plausibility of inference. Data extraction followed a structured template aligned with the review questions, capturing: system typology and context; management practices; indicators used; direction and magnitude of reported outcomes; and governance or institutional conditions. Evidence was then synthesised narratively across four thematic domains. To keep the manuscript within journal length constraints, detailed extraction tables and full PRISMA documentation can be provided as supplementary material.

Figure 1: PRISMA flow diagram summarising study identification, screening, eligibility, and inclusion.



DISCUSSION

The reviewed literature is geographically diverse and methodologically heterogeneous, combining field experiments, farm surveys, landscape assessments, and mixed-method case studies. Despite this diversity, findings cluster into four recurring themes: (i) typologies and design configurations, (ii) environmental performance, (iii) livelihood and social outcomes, and (iv) governance and scaling pathways. Across themes, outcome variation is consistently attributed to (a) management intensity (especially stocking rates, tree density, and ground-cover maintenance), (b) biophysical constraints (rainfall, soils, slope), and (c) socio-institutional conditions (tenure, labour, extension, and markets).

Typologies And Design Drivers

ASPS are commonly classified by the spatial relationship between trees and grazing areas (scattered trees in pasture, alley-based arrangements, boundary plantings, multi-strata homegardens), and by the intended functions of the tree component (fodder, timber, shade, soil improvement, or biodiversity habitat). Consistent with agroforestry typology literature, the same label can conceal substantial internal variation, so reported performance must be interpreted in relation to actual species composition and management practices (Nair, 1989, 1993, 2012). Design choices are shaped by household objectives, land availability, risk perceptions, and market conditions. Several studies highlight that systems are often adopted incrementally-starting with scattered shade/fodder trees and progressing toward more structured arrangements as farmers gain confidence and access to planting material or technical support (Degrande et al., 2012; Partey et al., 2017).

Environmental Performance And Ecosystem Services

A dominant finding is that the tree component can improve environmental performance when it increases ground cover, reduces erosive exposure, and supports nutrient cycling through litter and manure interactions. Reported benefits include improved soil organic matter, infiltration and moisture retention, reduced erosion, and moderated microclimate that can reduce heat stress for animals (Jose & Dollinger, 2019; Torralba et al., 2016). However, benefits are not automatic. Overgrazing, removal of understory vegetation, or poor species-site matching can negate gains and, in some cases, exacerbate degradation. Studies therefore emphasise the centrality of aligning stocking rates with forage productivity and seasonal variability-an operational framing of carrying capacity that links ecological limits with management decisions (Shrestha et al., 2018). Measurement approaches vary, ranging from plot-based soil and vegetation surveys to indicators of carbon stocks and biodiversity habitat, making cross-study comparison challenging and reinforcing the need for consistent indicator reporting.

Livelihoods, Economic Viability, And Equity

Many studies report that ASPS can contribute to more resilient livelihoods by diversifying products (e.g., fodder, fruit, timber, non-timber products) and smoothing seasonal income. Positive economic outcomes are more likely where tree products have accessible markets, where labour requirements are manageable, and where households can absorb delayed returns from tree establishment. Conversely, high upfront labour or opportunity costs, limited tenure security, and credit constraints reduce adoption incentives and can concentrate benefits among better-resourced farmers (Giusti et al., 2019; Malek & Verburg, 2017). Equity and inclusion emerge as cross-cutting issues: the distribution of costs and benefits is shaped by gendered labour roles, control over land and trees, and participation in farmer organisations. Participatory approaches and collective action can lower transaction costs and support learning, but they require supportive facilitation (Pretty, 2003; Scherr & McNeely, 2008).

Governance, Institutions, And Scaling Pathways

The literature depicts ASPS as socio-technical-ecological interventions that depend on enabling institutions. Commonly cited mechanisms include extension and farmer-to-farmer learning platforms, incentive schemes or payments linked to restoration and ecosystem services, tenure and tree-rights clarification, and integration of ASPS within broader land-use planning frameworks. Multi-actor governance arrangements-linking farmers, local government, NGOs, and private value-chain actors-are repeatedly associated with more sustained adoption and monitoring (Scherr & McNeely, 2008). Barriers to scaling include inconsistent policy signals, limited local capacity for technical assistance, and weak coordination between agricultural and environmental agencies. Several studies argue for adaptive governance that treats ASPS as long-term landscape transitions rather than short project cycles (Brogna et al., 2018; Andrade et al., 2017).

Table 1 summarizes the thematic synthesis and provides a compact mapping from land suitability variables to carrying capacity logic, the dominant evidence types, and planning implications. For policy and planning, this implies that land suitability zoning should incorporate governance feasibility-tenure clarity, local enforcement capacity, and coordination across agriculture, forestry, and watershed authorities-alongside biophysical metrics. Where these enabling conditions exist, climate-smart agroforestry is reported as a viable pathway to improve food security and resilience (Partey et al., 2017).

At governance scale, the literature converges on the proposition that conservation and production objectives can be co-managed in multifunctional landscapes, but only when incentives and rules are aligned across sectors. This is consistent with arguments for biodiversity-friendly agriculture that recognizes working landscapes as a core arena for conservation, not merely a spillover zone (Scherr & McNeely, 2008; Altieri, 2004).

Governance And Landscape-Level Integration

Extension and participatory mechanisms-such as farmer-to-farmer learning and locally adapted trials-are consistently framed as prerequisites for scaling agroforestry innovations. Case evidence from participatory dissemination highlights that adoption is higher when farmers co-design practices and when institutional support reduces transaction costs (Degrande et al., 2012; Giusti et al., 2019). This aligns with broader evidence on collaborative governance and co-management, where trust-building, facilitation, and shared rules are central to coordinating multi-actor landscape interventions (Ansell & Gash, 2007; Stringer et al., 2009; Ahrens et al., 2025).

Livelihood outcomes are reported through diversified income streams (livestock, timber, fruit, or ecosystem service payments), risk buffering, and improved resilience to climatic shocks. However, adoption is repeatedly conditioned by knowledge, labor availability, and short-term opportunity costs (e.g., delayed benefits from tree components). The evidence underscores the role of social capital and collective action in sustaining common resources and shared infrastructure (e.g., water points, grazing arrangements) (Pretty, 2003). Distributional outcomes and adoption barriers are not value-neutral; they are shaped by gendered roles, resource access, and local institutions, which can determine who benefits from cattle-related land interventions (Achandi et al., 2023; Abaynew et al., 2024).

Livelihoods, Adoption, And Social Learning

In several studies, GIS and remote sensing are used not only to map biophysical suitability, but also to target interventions to ‘where they work’ (e.g., erosion hot spots, riparian buffers, or degraded pasture blocks). These approaches are consistent with the broader environmental management literature that calls for spatially explicit indicators and monitoring to validate assumptions in suitability scoring (Brogna et al., 2018; Malek & Verburg, 2017). Where suitability mapping is applied in biodiverse or conservation-sensitive landscapes, studies stress the need to overlay ecological priorities and protected-area constraints to avoid biodiversity trade-offs (Anaya & Espírito-Santo, 2018; Hernandez Marentes et al., 2022).

Land suitability assessments in this evidence base commonly use multi-criteria evaluation (MCE) frameworks that integrate topography, soils, climate, and accessibility. At landscape scale, land system approaches help to capture how production systems co-evolve with markets, infrastructure, and land tenure-factors that can shift ‘suitable’ land into contested or high-risk areas. This is particularly relevant where cropland expansion competes with grazing space or tree cover. Frameworks that treat land as a coupled social-ecological system are better aligned with policy decisions because they make explicit the trade-offs across competing land uses (Malek & Verburg, 2017). Integrating land evaluation with conservation planning and local risk profiles is therefore a practical safeguard against maladaptive expansion (Anaya & Espírito-Santo, 2018; Hernandez Marentes et al., 2022).

Spatial Planning And Land Suitability Assessment

A repeated implication is that carrying capacity should be treated as a management variable rather than a fixed property of land. The evidence supports adaptive stocking, rotational grazing, and targeted supplementation as strategies to keep animal pressure aligned with pasture recovery, thereby protecting soil function and sustaining productivity over time (Jose & Dollinger, 2019).

The most direct bridge between land suitability and carrying capacity is the forage pathway: system designs that stabilize year-round biomass production reduce feed gaps and allow stocking decisions to follow seasonal supply. Reviews emphasize that trees influence pasture productivity via shade, altered soil moisture, and litter inputs, with outcomes ranging from neutral to positive depending on spacing, pruning, and grass species selection. In practical terms, carrying capacity estimates are most defensible when they combine (i) measured or modeled forage yield, (ii) utilization rates that avoid overgrazing, and (iii) seasonal adjustment to account for dry-season scarcity (Jose & Dollinger, 2019; Shrestha et al., 2018).

Forage Productivity And Carrying Capacity Pathways

From a land suitability perspective, the literature implies that ‘biophysical fit’ should be operationalized beyond static soil and climate classes by explicitly including risk factors that mediate environmental outcomes-particularly slope, erosion susceptibility, proximity to waterways, and seasonal rainfall concentration. These factors determine whether intensification raises land degradation risk or whether agro-silvopastoral designs deliver net regulating services under local constraints (Torralba et al., 2016; Brogna et al., 2018).

Across the reviewed studies, environmental performance is most consistently assessed through soil and water-related indicators (e.g., soil organic carbon, infiltration, erosion control, and nutrient cycling), alongside biodiversity co-benefits. Evidence indicates that integrating trees and managed grazing can reduce runoff and erosion on sloping or fragile land while improving soil structure and microclimate, but the magnitude of benefits is contingent on species choice, canopy density, and grazing intensity. Studies that synthesize ecosystem services in agroforestry highlight clear co-benefits (carbon storage, habitat provision, and regulating services), with trade-offs emerging when shade suppresses understory forage or when compaction increases under overstocking (Torralba et al., 2016; Shrestha et al., 2018; Brogna et al., 2018).

Environmental Performance And Ecosystem Services

Table 1: Thematic Synthesis Linking Land Suitability And Carrying Capacity Evidence In Agro-Silvopastoral Systems.

Theme	Key suitability / carrying capacity variables	Typical data and methods	Planning implications
Environmental performance	Slope, erosion risk, soil C, infiltration, riparian proximity	Field soil measures; ecosystem service synthesis; environmental indicators	Prioritize low-risk zones; embed erosion safeguards; monitor soil-water outcomes
Forage and carrying capacity	Forage yield, utilization rate, seasonal feed	Biomass sampling/modeling;	Use adaptive stocking; rotational grazing; plan

	balance, stocking rate	grazing management experiments; seasonal adjustment	for dry-season feed gaps
Spatial suitability planning	Topography, soils, climate, accessibility, land-use competition	GIS/MCE; land systems analysis; remote sensing monitoring	Target interventions spatially; validate scoring with time-series monitoring
Livelihoods and adoption	Labor, knowledge, market access, risk preferences, social capital	Case studies; participatory trials; mixed methods	Invest in extension and co-design; reduce adoption costs; support collective action
Governance and integration	Tenure clarity, cross-sector coordination, incentives, enforcement capacity	Policy analysis; institutional assessment; landscape governance literature	Align incentives across sectors; integrate watershed/biodiversity objectives into zoning

This synthesis reinforces a core message: ASPS performance is context-dependent and mediated by management and institutions. From a planning standpoint, land suitability should be framed as a ‘fit’ between site conditions (slope, soils, moisture, access), system design (tree species, spatial arrangement, forage base), and governance capacity (tenure, extension, markets). Treating suitability as purely biophysical risks recommending systems that are technically feasible but socially brittle. Conversely, treating adoption as purely behavioural underestimates ecological constraints and degradation risks.

Carrying capacity is similarly revealed as a design and governance issue. The literature consistently links environmental benefits to maintaining adequate ground cover and preventing chronic overgrazing-conditions that require stocking decisions informed by seasonal forage dynamics and supported by institutions that help farmers adjust practices. Where monitoring is absent or where policy incentives encourage herd expansion without parallel investments in forage, shade, and soil management, the ecological gains of tree integration can be reversed.

For Taluditi Subdistrict and similar settings in Gorontalo, the review suggests an applied pathway. First, spatial targeting should combine land suitability indicators with farmer knowledge and local rules on access and tree management, reducing conflicts and improving legitimacy. Second, program design should prioritise low-regret entry points (e.g., scattered fodder/shade trees, live fences) while building capacity for more structured silvopasture as learning accumulates. Third, governance design should be explicit: clarify tree rights, embed farmer organisations in decision-making, and align district-level agricultural support with environmental objectives to avoid contradictory signals. Finally, monitoring frameworks should be proportionate and practical, emphasising a small set of indicators that reflect both productivity and environmental safeguards.

Research gaps remain. Cross-study comparability is limited by inconsistent indicator sets and insufficient reporting of management intensity (especially stocking rates), which constrains inference relevant to carrying capacity. More longitudinal evidence is needed to capture temporal trade-offs and establishment phases. In addition, more attention is required to equity outcomes, including who benefits from ecosystem-service incentives and who bears labour burdens during transitions. For Indonesia, complementary national research on enteric methane mitigation reinforces that sustainability in cattle development also depends on feed-based interventions and innovation pathways that can be integrated with land-based planning (Badan Riset dan Inovasi Nasional [BRIN], n.d.).

CONCLUSION

Agro-silvopastoral systems offer a credible pathway to integrate cattle production with landscape restoration, but they are not a universal solution. The reviewed evidence indicates that environmental and livelihood benefits are most likely where tree and ground-cover components are maintained, grazing pressure is aligned with forage dynamics, and enabling institutions support learning, tenure security, and market access. For cattle development initiatives, this implies that land suitability and carrying capacity should be operationalised as integrated social-ecological design questions rather than stand-alone biophysical calculations. Future work for Taluditi should therefore couple spatial analyses with participatory governance and monitoring to ensure adoption, equity, and long-term performance.

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