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Systematic Review

Grass–Legume Mixtures for Fodder Production in Sub-Saharan African Drylands: A Systematic Review of Productivity, Nutritive Value, and Evidence Gaps

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Highlights

What are the main findings?

- Grass–legume mixtures were associated with increased fodder biomass in most of the reviewed yield studies, although responses varied among species combinations and environments.
- Nine studies reported higher crude protein or selected nutritional indicators in grass–legume mixtures, although responses varied among studies.

What are the implications of the main findings?

- Grass–legume mixtures offer a potential approach for improving fodder productivity and nutritive value in dryland livestock systems.
- Further research should address species compatibility, environmental variation and participatory on-farm evaluation.

Abstract

Feed scarcity and land degradation are major constraints to livestock production in the drylands of Sub-Saharan Africa (SSA). This systematic review assessed the most commonly studied grass and forage legume species and how grass–legume mixtures affect forage yield and nutritive value in SSA drylands. Following PRISMA 2020 guidelines, Web of Science and Scopus were searched for peer-reviewed studies. A total of 32 studies met the inclusion criteria, covering ten countries, with most studies conducted in Kenya, Nigeria, Tanzania, and Ethiopia. The review identified 91 forage species (55 legumes, 36 grasses), with *Centrosema pubescens* and *Chloris gayana* being the most frequently studied legume and grass species, respectively. Of the 20 studies reporting dry matter yield in grass–legume mixtures, 17 (85%) showed increases of 13–500% compared with grass monocultures, while three (15%) reported decreases of 2–37%. Nine studies compared forage nutritive value, with reported crude protein of mixtures ranging from 9.6% to 14.4% of DM. The evidence base was limited by substantial heterogeneity in species combinations, management practices, the small number of contemporary studies, and limited assessment of socio-economic factors influencing

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adoption. Further research should prioritize long-term, participatory and farmer-managed evaluations across contrasting environmental and socio-economic contexts.

Keywords: drylands; pastures; fodder; forage legumes; grass–legume mixtures; sub-Saharan Africa

1. Introduction

Drylands in Sub-Saharan Africa (SSA) support pastoral and agropastoral livelihoods that depend heavily on livestock and natural rangeland resources [1,2]. However, these systems face persistent challenges associated with seasonal feed shortages, recurrent droughts, climate variability, and declining rangeland productivity. Feed scarcity is particularly problematic during prolonged dry periods, when both forage quantity and nutritional quality decline, affecting livestock growth, reproduction, health, and household livelihoods. Recent reviews have highlighted the interconnected effects of land degradation, climatic pressures, and socio-economic conditions on livestock productivity in SSA [3,4].

Livestock production is an important component of pastoral and agropastoral livelihoods in SSA drylands [5,6]. However, feed availability fluctuates considerably across seasons, with forage shortages and declining nutritional quality during dry periods limiting livestock productivity [7,8]. Prolonged droughts can intensify these shortages, increasing the risk of livestock weight loss, poor reproductive performance, disease, and mortality [9–11]. These challenges are compounded by limited capacity to conserve surplus wet-season forage for use during dry periods [12–14].

Rangeland degradation further constrains forage production through the loss of vegetation cover, changes in species composition, soil erosion, and declining biological and economic productivity [15–17]. Its drivers include recurrent drought, climate variability, land-use change, grazing pressure, and changes in resource management [15,16,18]. The resulting decline in forage availability can undermine livestock production and increase pressure on already limited grazing resources [15,16]. Addressing these challenges requires management approaches that improve forage quantity and nutritional quality while maintaining soil function and supporting the resilience of livestock-dependent livelihoods [15,16,18].

Sustainable restoration and management practices are needed to increase forage production and strengthen rangeland and livelihood resilience. Reseeding degraded rangelands with suitable grasses, sometimes in combination with forage legumes, has been promoted as a means of restoring vegetation cover and improving forage productivity [19–21]. Although grass-only reseeding is commonly used [19–21], incorporating legumes may offer additional benefits by diversifying forage resources and improving nutritional quality.

Grass–legume mixtures can provide complementary contributions to forage production, with grasses contributing substantial biomass and legumes increasing forage protein concentration and supplying nitrogen through biological nitrogen fixation [18,22,23]. Differences in species growth patterns and seasonal responses may influence forage availability and quality over time [8], while complementary root systems may improve soil protection, depending on species characteristics and environmental conditions [8]. Furthermore, nitrogen released through legume decomposition may become available to companion grasses because grasses and legumes differ in their nutrient requirements and resource-acquisition strategies [22]. However, these potential benefits are not universal and depend on species compatibility, relative growth rates, establishment success, rainfall variability, soil fertility, and management practices. Therefore, evaluating grass–legume mixtures against grass monocultures is essential to determine whether they improve forage yield and nutritional

quality and to identify the environmental and management conditions under which these benefits are most likely to occur.

The potential benefits of grass–legume mixtures depend not only on their ecological performance but also on whether livestock producers can establish and manage them under local conditions. Access to suitable and affordable seed, availability of labour for land preparation and planting, establishment costs, and access to technical advice can influence adoption [4,24,25]. In smallholder farming systems in Kenya, forage adoption has also been associated with land tenure, access to education, market proximity, and household and farm characteristics [26]. In pastoral and agropastoral systems, management decisions must additionally account for seasonal livestock mobility, access to grazing resources, and the institutional arrangements governing land use [27]. These constraints may affect the feasibility and sustainability of grass–legume interventions, even where forage or soil benefits have been demonstrated experimentally. Evaluating their contribution to dryland livestock systems therefore requires attention to both ecological outcomes and the practical, socioeconomic, and institutional conditions under which farmers and pastoralists can adopt and maintain them [4].

Despite these recognized benefits, evidence from SSA drylands remains fragmented across forage species, management practices, and ecological conditions. Most available studies focus on individual experiments or specific forage systems [4], limiting broader understanding of mixture effects on forage productivity, nutritive value, and soil restoration. A systematic synthesis of this evidence is therefore needed to support restoration initiatives and sustainable livestock production.

Previous reviews have examined tropical forage technologies and their contributions to livestock productivity, soil quality, and household livelihoods across Sub-Saharan Africa [4]. However, these broader syntheses do not necessarily provide a focused assessment of grass–legume mixtures specifically within dryland environments, where water limitation, seasonal feed shortages, and variable management conditions influence forage performance. This review synthesises field-based evidence on the species used, comparative forage yield and nutritional quality, and the distribution of research across countries and publication periods.

This systematic review examined the evidence on grass–legume mixtures for forage production in Sub-Saharan African drylands. Specifically, it addressed the following question: Compared with grass monocultures or other reported control treatments, how do grass–legume mixtures affect forage dry matter yield and forage nutritive value?. The review aimed to: (i) identify the grass and legume species most frequently investigated in SSA drylands; (ii) evaluate reported differences in forage yield and nutritional quality between grass–legume mixtures and grass monocultures; and (iii) identify ecological, management, and socio-economic knowledge gaps that should guide future research.

2. Materials and Methods

2.1. Protocol and Registration

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [28]. The review was not prospectively registered in a systematic review registry. A formal review protocol was not prepared before the review commenced. The review methods and eligibility criteria are described in this manuscript, and the review was reported in accordance with the PRISMA 2020 guidelines.

2.2. Literature Search Strategy

Peer-reviewed articles were identified through comprehensive searches of Clarivate Web of Science and Scopus. The original searches were conducted on 24 July 2024, and the searches were updated on 23 October 2026 to identify relevant publications published since

the original search. In Web of Science, the updated search was restricted to the period from 25 July 2024 to 23 October 2026. In Scopus, the search was updated to include publications from 2024 onwards because the database interface did not allow the same exact date range to be specified. The two databases were selected for their broad coverage of agricultural and environmental sciences and their indexing of the peer-reviewed scholarly literature. The original search included all publication years, while the updated searches focused on the additional literature published since July 2024. The updated searches retrieved 20 records: 15 from Web of Science and five from Scopus.

The search query in Web of Science was:

TS = ((Grass* NEAR/3 (multicrop* OR "multi crop*" OR multi-crop* OR intercrop* OR "inter crop*" OR inter-crop* OR mix*)) OR (legume* NEAR/3 (multicrop* OR "multi crop*" OR multi-crop* OR intercrop* OR "inter crop*" OR inter-crop* OR mix*))) AND TS= (fodder* OR hay* OR forage OR "livestock feed" OR pasture*) AND TS= (Dryland* OR Rangeland* OR arid* OR semi-arid* OR semiarid* OR "semi arid*" OR ASAL*) AND (Sub-Sahara* OR Subsahara* OR sub-Sahara* OR "sub sahara*" OR africa*).

The search query in Scopus was:

TITLE-ABS-KEY(((Grass* W/3 (multicrop* OR "multi crop*" OR multi-crop* OR intercrop* OR "inter crop*" OR inter-crop* OR mix*)) OR (legume* W/3 (multicrop* OR "multi crop*" OR multi-crop* OR intercrop* OR "inter crop*" OR inter-crop* OR mix*)))) AND TITLE-ABS-KEY((fodder* OR hay* OR forage OR "livestock feed" OR pasture*)) AND TITLE-ABS-KEY((Dryland* OR Rangeland* OR arid* OR semi-arid* OR semiarid* OR "semi arid*" OR ASAL*)) AND TITLE-ABS-KEY((Sub-Sahara* OR Subsahara* OR sub-Sahara* OR "sub sahara*" OR africa*)).

2.3. Study Selection

During the initial search, a total of 276 record search results retrieved from Web of Science and Scopus were imported into R version 4.2.3 [29] using the import_results function from the litsearchr package [30] to facilitate systematic management of bibliographic records and identification of duplicate records. The imported records were subsequently screened manually by the review team. Nine duplicates were identified and removed using remove_duplicates function with exact title matching, leaving 267 unique articles for screening.

The inclusion criteria comprised peer-reviewed journal articles reporting field-based research on grass–legume mixtures for forage or pasture production in drylands of Sub-Saharan Africa. Eligible studies were required to report outcomes related to forage yield and nutritional value and to be published in English. Exclusion criteria included non-peer-reviewed publications, such as theses, reports, and conference proceedings; studies focusing on food-crop intercropping; studies conducted outside Sub-Saharan Africa; and non-field experiments, including greenhouse and laboratory-only studies. Review articles, theoretical and narrative studies, articles published in languages other than English, and studies with incomplete or duplicated data were also excluded. The review focused on grass–legume mixtures for forage or pasture production, including mixtures involving herbaceous legumes and, where applicable, tree legumes in hedgerow systems. Studies focusing primarily on the production or use of brush, shrub, or arboreal legumes without an associated grass–legume mixture were excluded.

For this review, "drylands" refers to water-limited environments in Sub-Saharan Africa rather than to dryland farming practices [1]. The term is used as an overarching ecological and geographical descriptor encompassing arid, semi-arid, and dry sub-humid environments, in which forage production is constrained by limited and/or seasonally variable water availability. The search strategy included terminology used to describe these en-

vironments in the literature, including dryland, rangeland, arid, semi-arid, and ASAL. Because the primary studies varied in how they described their environmental conditions, the term "drylands" was used as the overarching scope of the review rather than assigning all studies to a single climatic class. Where climatic information was available, rainfall, temperature, and other reported environmental characteristics were extracted to describe the environmental range represented by the included studies.

Screening was distributed among five team members using the effort_distribute function in litsearchr, with each reviewer screening approximately 20% of articles. Of 267 unique articles screened, 117 met criteria for full-text assessment; 150 were excluded primarily for not being peer-reviewed or relevant. Of 117 articles identified for full-text review, only 54 were accessible through the Swedish University of Agricultural Sciences (SLU) library and other online sources. The remaining 63 articles could not be accessed despite extensive searches through institutional subscriptions, interlibrary loan requests and public repositories. These articles were excluded because their eligibility and relevant data could not be verified. During the original full-text screening, 23 articles were excluded for the following reasons: studies conducted outside SSA ($n = 4$), food-crop intercropping ($n = 3$), non-field experiments ($n = 1$), reports ($n = 2$), review articles ($n = 2$), non-English publications ($n = 2$), duplicate content ($n = 1$), and studies with incomplete data ($n = 8$). In the updated search, 20 records were retrieved, and five duplicates were removed, leaving 15 unique records. Three records were retained after title-and-abstract screening; following assessment against the predefined eligibility criteria, only one article met the criteria and was eligible for inclusion. Consequently, 32 studies met all inclusion criteria (Figure 1).

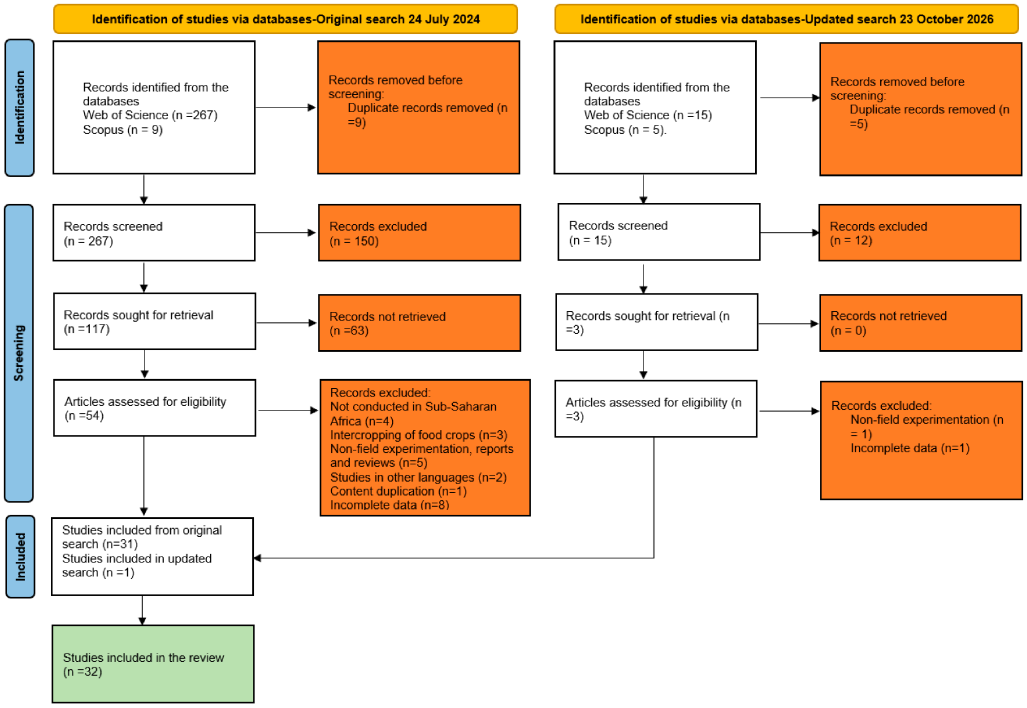


Figure 1. PRISMA flow diagram for systematic reviews.

2.4. Data Extraction

Data were extracted using a predefined and standardized framework (Supplementary File S2), which was developed and discussed among all authors before data extraction. The authors agreed on the themes and variables to be extracted, including publication year, study location, climatic characteristics, forage species, experimental treatments, forage yield, nutritive value parameters, and other relevant study characteristics. The first author then

extracted and populated the agreed framework using information reported in the included studies. Following the initial extraction, the extracted data were reviewed collectively by all authors. Where discrepancies, inconsistencies, or uncertainties were identified, the relevant information was rechecked against the original publication and corrected where necessary, providing an additional quality-control step to reduce extraction errors.

Where methodological information was not reported, the corresponding assessment was classified as unclear rather than assumed to be adequate or inadequate. For example, the absence of information on replication or treatment randomisation was recorded as unclear unless the study explicitly described a design that raised concerns. Criteria that were not relevant to a particular study design were classified as not applicable. These distinctions were retained when interpreting the evidence, particularly for older publications with limited methodological reporting.

2.5. Risk of Bias Assessment

The methodological quality of the included studies was assessed narratively based on key features of experimental design and reporting. Information relevant to methodological quality was documented using a structured data extraction Excel file (Supplementary File S2), which captured study characteristics including publication details, study location, environmental conditions, experimental design, treatment characteristics (e.g., grass–legume mixtures), number of replications, management practices, measured outcomes (e.g., biomass production, forage nutritive value and vegetation parameters), and reported research limitations. These characteristics were considered during the interpretation of the findings. Given the diversity of study designs and the predominance of field-based agronomic experiments spanning eight decades, no standardized risk-of-bias tool was considered appropriate. Instead, a narrative methodological quality assessment was undertaken using information extracted from each study. The assessment considered the clarity of study objectives, description of the experimental design, use of appropriate controls, replication, treatment allocation or randomization (where reported), statistical analyses, completeness of outcome reporting, and reporting of study limitations. These characteristics were recorded during data extraction and considered during interpretation of the findings (Supplementary File S4).

2.6. Data Synthesis and Standardization

Bibliographic records were imported and managed in R version 4.2.3 [29] using the import_results function from the litsearchr package [30]. Extracted study data were subsequently organised and descriptively summarised using R and Excel. The authors interpreted the extracted evidence, compared findings across studies, and identified patterns and evidence gaps based on the characteristics and results reported in the included studies. Publication year, study location, climatic characteristics, experimental design, number of replicates, treatment structure, and comparator were recorded as study-level characteristics. For reported outcomes, the treatment means, comparator means, and associated units were extracted where available.

Reported measurements were converted to common units when the original units and the information required for conversion were available. Dry matter yield was standardised to t ha^{-1} for reporting, while crude protein yield was expressed in kg ha^{-1}. Where the original unit, measurement basis or necessary conversion information was missing or ambiguous, values were not converted by assumption. Such information was recorded as unreported or unavailable, and the affected observation was excluded from calculations requiring a common unit while being retained in the descriptive synthesis where appropriate. No missing numerical values were imputed. Other measurement units standardized were:

Temperature: Fahrenheit to Celsius (°C = (°F − 32) × 5/9), Rainfall: inches to millimeters (×25.4), Altitude: feet to meters (×0.3048).

The synthesis included counts and proportions of studies reporting increases, decreases or no clear change in forage yield and nutritive value, together with ranges of reported outcomes where comparable data were available. Where the necessary information was reported, changes in forage yield and crude protein were calculated relative to the relevant grass monoculture comparator. Measurement units were standardised where conversion was possible from the information provided in the original publication. A formal meta-analysis and pooled effect estimates were not undertaken because of heterogeneity in experimental designs, species combinations, environmental conditions, outcome definitions and reporting formats.

Yield and quality parameters

The principal forage yield and quality parameters extracted from the reviewed studies are described below. Where reported, these variables were determined using standard analytical procedures and equations:

Dry matter (DM)

Determined as the mass of oven-dried biomass per hectare.

Crude protein (CP, %)

$$CP\ (\%) = N(\%) \times 6.25$$

$$Crude\ protein\ yield(\text{CPY, kg ha}^{-1}) = \frac{CP(\%)}{100} \times DM\ (\text{kg ha}^{-1})$$

Organic matter digestibility (OMD, %)

Calculated using gas-production-based prediction; $OMD(\%) = 18.53 + 0.9239GP + 0.0540CP$ where GP stands for Gas Production (mL 200 mg^{-1} DM) and CP is Crude Protein (g kg^{-1} DM).

Metabolizable energy (ME, MJ kg^{-1} DM)

$$ME(\text{MJkg}^{-1}\ \text{DM}) = 14.78 - 0.0147ADF$$

where 'ADF' stands for acid detergent fibre expressed as g kg^{-1} DM.

Fibre fractions, including neutral detergent fibre (NDF) and acid detergent fibre (ADF), were determined following [31] and expressed as g kg^{-1} DM. Total ash content was measured by combusting samples in a muffle furnace at 550 °C for 3 h, following standard procedures [32,33].

Species were analysed at species level. Because included studies differed substantially in forage species, experimental designs, outcome measures, and management practices, a quantitative meta-analysis was not appropriate. No subgroup analyses, sensitivity analyses, assessment of reporting bias, or formal certainty-of-evidence assessment were undertaken.

The unit of synthesis was the individual included study/publication. Each included study was counted once when reporting the number of studies contributing to a particular outcome. Multiple outcomes, species combinations or treatment comparisons reported within the same study were retained as study-level observations but were not treated as independent studies. Because the review did not conduct a quantitative meta-analysis, no statistical weighting of effect estimates or adjustment for dependence among effect estimates was undertaken.

3. Results

3.1. Study Characteristics

The database searches were conducted in the year 2024 and updated in the year 2026. The original search identified 31 studies published between 1935 and 2022. Following the search update on 23 October 2026, one additional eligible study [34] was included, bringing the total to 32 studies across ten Sub-Saharan African countries (Figure 2). Kenya

contributed the largest proportion (28%), followed by Nigeria (22%), Tanzania (16%), and Ethiopia (9%). Rhodesia (present-day Zambia/Zimbabwe), Malawi, Ghana, and Swaziland (present-day Eswatini) each accounted for 3% of studies (Figure 2).

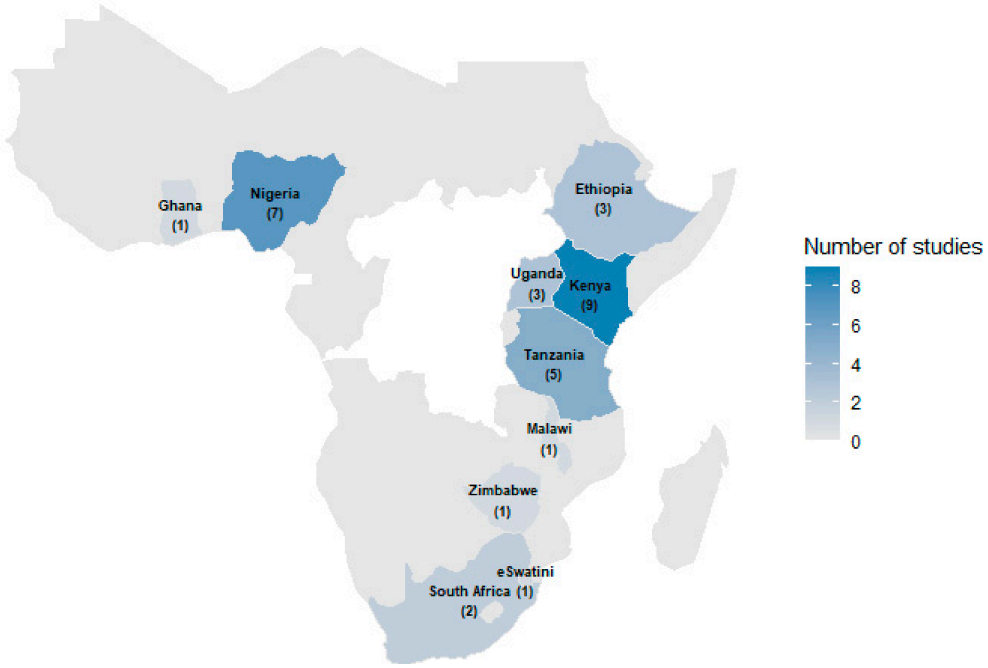


Figure 2. Geographical distribution of studies by country.

The highest number of publications ($n = 4$) was recorded in 1995. The inclusion of Nyaga et al. [34] adds a contemporary field study, but the overall evidence base remains historically concentrated, with relatively few studies published in recent decades (Figure 3).

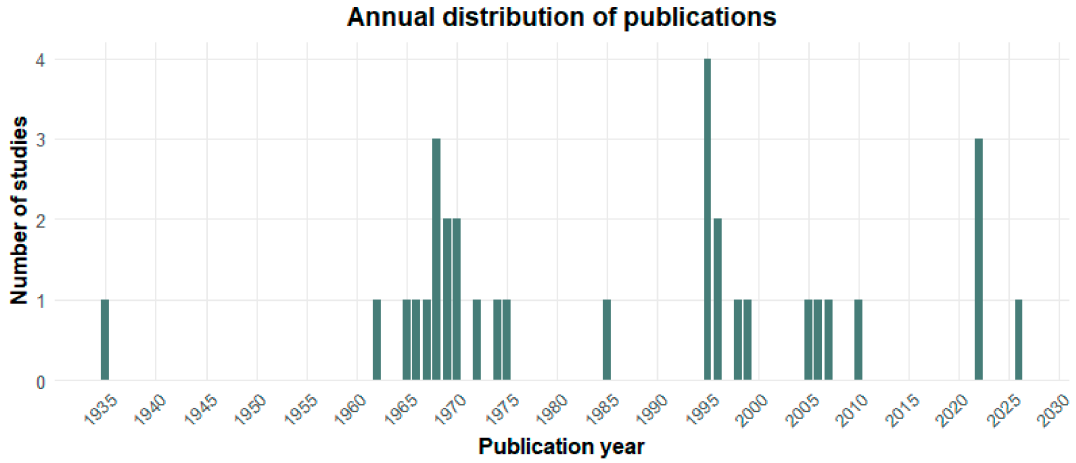


Figure 3. Annual distribution of included studies by publication year.

Agroecological conditions were reported in only 21 of 32 studies, while eleven studies lacked sufficient climate data for classification. Across the 21 studies with sufficient climate data, mean monthly temperature ranged from 19.6 °C to 38.3 °C, and annual rainfall varied considerably from 267 mm to 2091 mm (Figure 4), reflecting the wide range of dryland environments represented in the review.

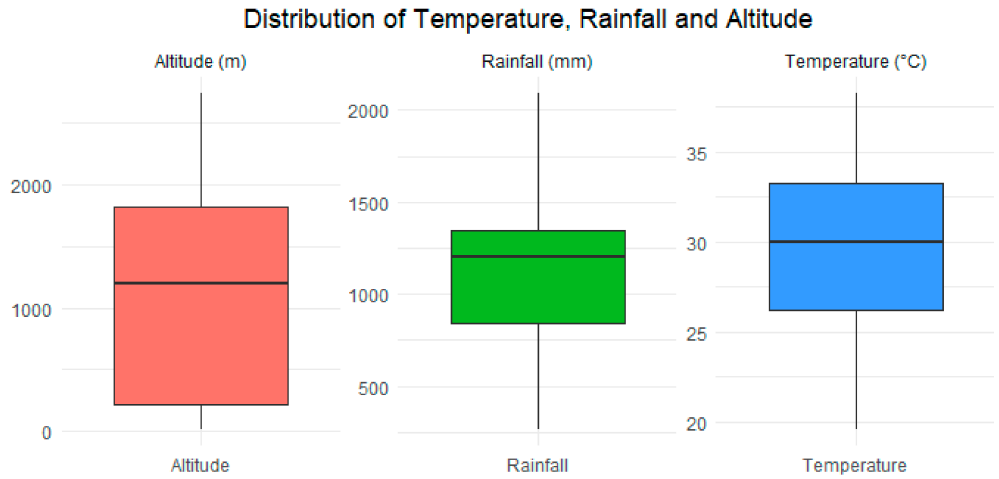


Figure 4. Distribution of reported temperature, rainfall and altitude among the 21 of 32 included studies with sufficient environmental information. Eleven studies were excluded from this visualization because sufficient climate information was not reported. Boxes indicate the interquartile range, horizontal lines indicate the median, and whiskers show the data spread.

3.2. Commonly Studied Species

Across the 32 studies, 91 forage species were evaluated, comprising 55 forage legumes and 36 grass species (Figures 5 and 6). This diversity reflects the broad range of forage options investigated for dryland pasture improvement; however, research has concentrated on relatively few species.

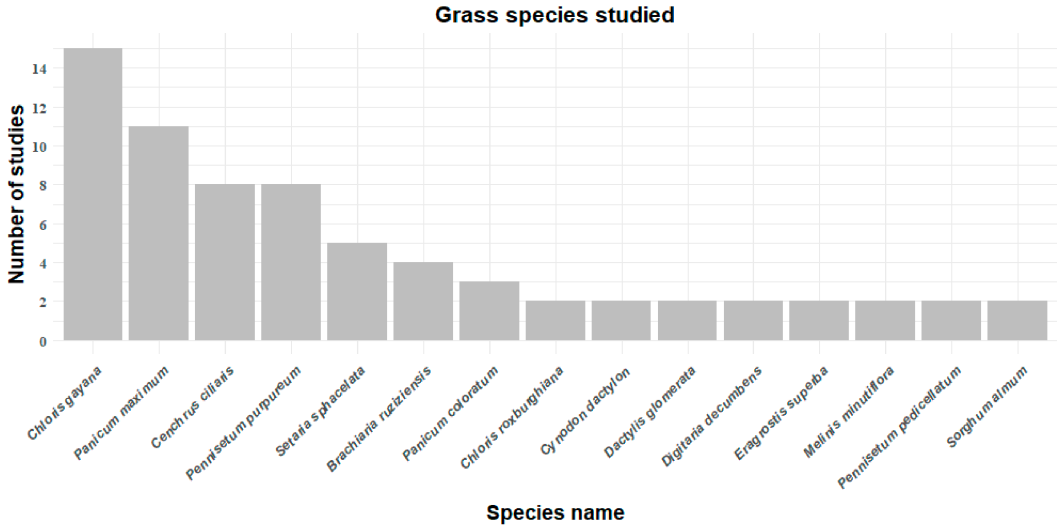


Figure 5. Grass species reported in at least two studies.

The most frequently studied grass species were *Chloris gayana* (Rhodes grass), which was reported in 15 studies, followed by *Panicum maximum* (Guinea grass) in 11 studies and *Cenchrus ciliaris* (Buffel grass) and *Pennisetum purpureum* (Napier grass) in 8 studies.

The most frequently studied forage legume species were *Centrosema pubescens* and *Desmodium uncinatum*, which were reported in 7 studies, followed by *Glycine javanica*, *Medicago sativa* and *Stylosanthes gracilis*, each of which was reported in 6 studies.

The preponderance of these species reflects their high adaptability to dryland conditions, suitability for mixed pasture systems, ability to enhance soil fertility, and contribution to improved forage quality [35].

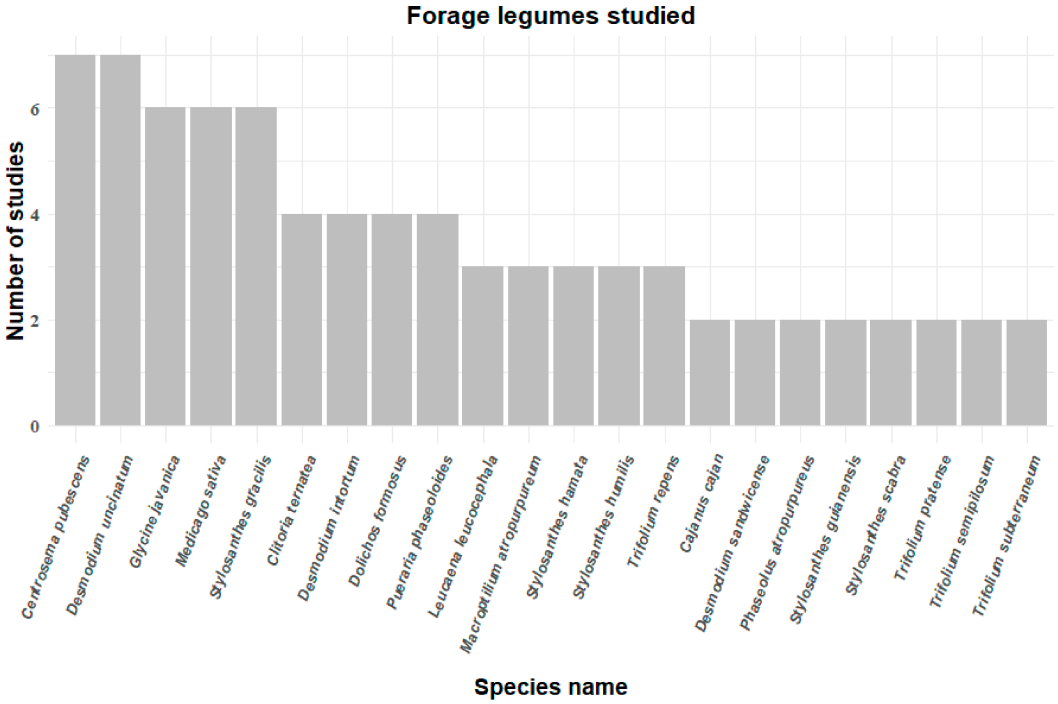


Figure 6. Forage legume species reported in at least two studies.

3.3. Effects on Dry Matter Yield

Of the 20 studies reporting biomass yield, 17 (85%) showed increased dry matter yield when grasses were grown in mixtures with forage legumes compared to grass monocultures (Table 1). Yield increases across the studies ranged from 13% [36] to more than 500% [37], depending on the species combination, environmental conditions, and management practices. Overall, biomass yields of grass–legume mixtures ranged from 2.2 to 26.1 t ha^{-1}. The highest reported biomass yield (26.1 t/ha) was obtained from a multispecies grass–legume mixture comprising *Panicum maximum* (sown at 5.6 kg/ha) and eight forage legumes: *Glycine javanica* (2.2 kg/ha), *Trifolium massaiense* (0.6 kg/ha), *Desmodium sandwicense* (2.2 kg/ha), *Medicago sativa* (1.1 kg/ha), *Desmodium uncinatum* (1.1 kg/ha), *Trifolium rueppellianum* (0.6 kg/ha), *Trifolium semipilosum* (0.6 kg/ha), and *Clitoria ternatea* (2.2 kg/ha) [38]. The mixture therefore comprised one grass and eight legume species, with a combined sowing rate of approximately 16.2 kg/ha. These values represent the reported sowing rates of the individual species rather than their proportions by established plant density. The lowest yield (2.2 t ha^{-1}) was reported for *Cenchrus ciliaris* combined with *Glycine javanica* [39]. The forage legume biomass yields ranged from 4.5 to 21.1 t ha^{-1}, with *Dolichos formosus* producing the highest yield [37] and *Centrosema pubescens* the lowest [40]. Grass biomass yields ranged from 1.5 to 22.5 t ha^{-1}, with the highest yield recorded for *Chloris gayana* [38] and the lowest for *Panicum maximum* [41]. Additionally, water harvesting through micro-catchments improved dry matter yields by 32% in larger catchments.

Negative interactions: Three of the 20 studies reporting yield comparisons (15%) reported lower yields in grass–legume mixtures than in grass monocultures, with reductions of 2–37%. These reductions were attributed to factors including interspecific competition, species-specific growth characteristics, planting patterns, and environmental conditions. In some experiments, *Brachiaria ruziziensis*, *Cynodon dactylon*, and *Panicum maximum* competed strongly with companion legumes, reducing them to only a small proportion of the sward [42]. However, these species also occurred in successful mixtures, indicating that competitive outcomes were context-dependent rather than attributable solely to species iden-

tity. Where reported, differences in sowing ratio, planting density, spatial arrangement and environmental conditions were therefore considered when interpreting negative responses.

Table 1. Effects of grass–legume mixtures on biomass/dry matter yield.

Comparison	Key Findings	References
Grass–legume vs. grass only ($n = 20$)	Eighty-five per cent (85% of the studies showed positive effects (13–500% yield increase), while 15% reported negative effects (2–37% yield decrease) when grasses were grown in mixtures with forage legumes compared to grass pure stands.	[32–34,36–41,43–53]
Grass–legume vs. other grass–legume mixtures ($n = 9$)	Some grass–legume mixtures yielded more biomass than others, depending on climate, species combination, management and planting pattern. Biomass yield ranged from 2.2 to 26.1 t ha^{-1}.	[36–38,43,46,48,50,54,55]
Specific species/other biomass information ($n = 10$)	Forage legume yield ranged from 4.5–21.1 t ha^{-1} while grass yield ranged from 1.5–22.5 t ha^{-1} across the studies. Competition from aggressive grasses like *Bracharia* sp. and *Cynodon* sp. suppressed legume persistence. The use of micro-catchments improved dry matter yield, where bigger micro-catchments increased grass dry matter yields by 32%.	[36–38,41,42,46,50,52,54,56,57]

Abbreviation: t ha^{-1}, tonnes per hectare. Note: The sample sizes shown in the table represent the number of studies contributing data to each specific comparison group and are not mutually exclusive; therefore, they do not sum to the total number of included studies ($n = 32$).

3.4. Effects on Forage Nutritive Value

Grass–legume mixtures consistently improved the nutritive value of forage compared with grass monocultures, although the magnitude of the improvement varied among studies and indicators (Table 2). Crude protein (CP) concentration of grass–legume mixtures increased by 56–81% relative to sole grass stands [52], with mixture CP concentrations ranging from 9.6–14.4% of dry matter (DM) and CP yields reaching up to 0.67 t ha^{-1}. In a comparison of Napier grass (*Pennisetum purpureum*) and Napier grass mixed with *Stylosanthes scabra* cv. Seca, effective degradability was higher in the mixture (38.7%) than in sole Napier grass (36%). Rumen degradability at 48 h and 120 h was also higher in the mixture, reaching 61% and 71% of DM, respectively, compared with 53% and 68% in sole Napier grass. The mixture also had higher organic matter digestibility (59.2% versus 52.2%), and metabolizable energy (8.41 versus 8.21 MJ kg^{-1} DM) [33]. Grass–legume mixtures generally had lower fibre fractions than grass pure stands, indicating improvements in both protein supply and overall forage quality.

Nutritional differences were also evident among forage species (Table 2). Legumes generally contained substantially higher CP concentrations (12–22% of DM) than grasses (2–11% of DM) and supplied approximately three to four times more CP than grasses, contributing more than 50% of the total CP in the mixtures. For example, *Cynodon nlemfuensis* mixed with *Pueraria phaseoloides* had a CP concentration of 12.5%, compared with 6.9% in the corresponding pure grass stand [52]. While in another study, a mixture of *Centrosema*

pubescens and *Brachiaria mutica* had a Crude Protein content of 14.4% [41]. Similarly, *Pennisetum purpureum* mixed with *Stylosanthes scabra* increased CP to 9.9%, compared with 8.1% in pure Napier grass [33]. In hedgerow systems, tree legumes such as *Leucaena leucocephala* and *Gliricidia sepium* also provided relatively high CP concentrations of 21–23% [51].

Table 2. Effects of grass–legume mixtures on forage nutritive value.

Comparison	Key Findings	References
Grass–legume mixtures vs. pure stands ($n = 9$)	Grass–legume mixtures showed consistently superior forage quality compared to grass pure stands, with values across the reviewed studies ranging from 36% to 38.7% of DM for effective degradability *, 68–71% of DM for rumen degradability *, 8.2–8.4 MJ kg^{-1} DM for metabolizable energy, and 52.2–59.2% for organic matter digestibility *. Fibre fractions and ash content were higher in pure stands than in mixtures.	[33,37,39,40,46,51,52,58,59]
Grass–legume mixtures vs. other mixtures ($n = 6$)	Forage nutritive value varied among the different species combinations. Some grass–legume mixtures yielded higher biomass without compromising nutritional qualities such as crude protein and digestibility, thus providing a better balance between forage quantity and quality compared to other combinations. The crude protein content in mixtures ranged from 9.6% of DM to 14.4% of DM. The fibre fractions were recorded as ADF (43.6–43.9%), NDF (68.8–69.1%), lignin (3.6–3.8%) and ash content (14.8% to 14.9%) of the forage dry matter.	[33,36,39,47,48,52]
Specific species/other information ($n = 10$)	Legumes had higher crude protein of 12–22% of DM, with grasses only consisting of 2–11% of DM. The legumes had a higher contribution to protein production, supplying 3–4 times more of the mixture's total crude protein than the grasses. Ether extract for legumes ranged from 2.1–2.6%, Neutral Detergent Fibre (NDF) 69.9–72.5%, ADF 38.4–42.2% and Acid Detergent Lignin of up to 12.7% The nitrogen fixation of legumes varied from 3–175 kg N ha^{-1} $year^{-1}$ depending on species.	[32,37,40–42,46,48,50,52,60]

Abbreviations: ADF, acid detergent fibre; DM, dry matter; and NDF, neutral detergent fibre. Note: The sample sizes shown in the table represent the number of studies contributing data to each specific comparison group and are not mutually exclusive; therefore, they do not sum to the total number of included studies ($n = 32$). * Definitions: Organic matter digestibility is the proportion of the organic matter in a feed that is digested by an animal, representing the organic fraction that is not excreted in faeces. Rumen degradability is the extent to which a feed component is broken down by microbial activity in the rumen over a specified period. Effective degradability measures the extent to which a feed is degraded by microorganisms in the rumen of a ruminant animal.

Energy content also showed modest improvements in some mixtures. For example, *Brachiaria mutica* combined with either *Centrosema pubescens* or *Pueraria phaseoloides* had an ME value of 10.0 MJ kg^{-1} DM, compared with 9.9 MJ kg^{-1} DM in pure grass [40]. Overall, these findings indicate that incorporating legumes into grass-based forage systems can enhance protein concentration, digestibility, energy supply, and fibre quality, thereby improving the nutritional value of forage for livestock.

4. Discussion

4.1. Overview of Studies and Temporal Patterns

This systematic review reveals that research on grass–legume mixtures in SSA drylands spans nine decades (1935–2026), with a notable scarcity of recent studies (only five since 2010). The small number of studies published after 2010 may reflect several factors, although the available evidence does not allow the relative importance of these explanations to be determined. These may include shifts in forage research priorities, increasing emphasis on alternative livestock-feed interventions, difficulties associated with establishing and maintaining grass–legume mixtures under variable dryland conditions, limited long-term field research infrastructure, and challenges in publishing locally generated agronomic evidence in internationally indexed journals. The absence of recent studies should therefore not necessarily be interpreted as evidence that grass–legume mixtures are no longer relevant, but rather as an indication of an important evidence gap. Most studies were researcher-managed on-station trials with inorganic fertilizers, rather than on-farm or rangeland-applied trials. This research gap is concerning given the urgent need for sustainable rangeland restoration strategies in the context of climate change, land degradation, and growing livestock populations [16,18]. The historical concentration of research may not adequately reflect contemporary challenges, including climate change impacts, evolving livestock systems, and socio-economic constraints faced by pastoral communities.

4.2. Species Diversity and Research Concentration

The 91 forage species identified across the included studies represent the range of grasses and legumes evaluated in the available evidence, but should not be interpreted as representing the full forage biodiversity of SSA drylands. However, research has concentrated on a limited number of species: *Chloris gayana*, *Cenchrus ciliaris*, *Panicum maximum*, *Pennisetum purpureum*, *Centrosema pubescens* and *Desmodium uncinatum* dominated the literature. This concentration may reflect historical introduction and promotion of these species by agricultural research systems; agronomic suitability for researcher-managed trials and availability of seed and propagation materials. The relatively limited number of species represented in the evidence base also highlights a potential research gap, as many native forage species may remain under-studied in experimental grass–legume systems.

However, it may also indicate neglect of locally adapted native species and underutilised genetic resources that could offer greater resilience and adaptation to local conditions [35]. Research should expand beyond the "usual suspects" to evaluate a broader portfolio of species, particularly underutilised native legumes and grasses, to diversify forage options and enhance resilience.

4.3. Grass–Legume Mixtures Improve Yield, but Not Universally

The finding that 85% of studies reported yield increases of 13–500% from grass–legume mixtures aligns with global evidence on the benefits of species mixtures [8,61]. The yield advantage can be attributed to complementary resource use, including differences in rooting depth, where grasses generally have fibrous and shallow root systems while legumes tend to develop deeper taproots, as well as differences in canopy architecture that reduce light

competition [62]. The species also differ in nutrient-acquisition strategies, with legumes contributing through biological nitrogen fixation and grasses efficiently capturing available soil nitrogen.

Facilitative interactions may further contribute to the increased productivity of grass–legume mixtures. Legumes can provide nitrogen to grasses through decomposition and root exudates, while grasses provide structural support and create favorable microclimates within the mixture. Increased species diversity may also provide "insurance effects" against environmental stress, helping to maintain productivity under variable conditions. The predominance of positive yield responses should also be interpreted in light of potential publication and selective-reporting biases. Studies reporting positive or statistically significant effects may be more likely to be published or emphasized than studies reporting null or negative responses. The small number of studies contributing comparable yield outcomes also limits the ability to assess the extent of such bias statistically. Consequently, the observed proportion of studies reporting yield increases should not be interpreted as an unbiased estimate of the probability that grass–legume mixtures will increase forage production.

On the other hand, 15% of the studies reported yield decreases of 2–37%, demonstrating that positive interactions are not universal. Negative outcomes occurred when aggressive grasses, such as *Brachiaria*, *Cynodon*, and *Panicum*, competitively excluded legumes [42,63]. For example, ref. [64] found that lucerne (*Medicago sativa*) outcompeted grasses in some cases due to its deeper rooting while suboptimal planting patterns and management practices, including inappropriate grass-to-legume seeding ratios, uneven seed distribution, poor timing of planting, inadequate weed control, and inappropriate cutting or grazing management, also contributed to reduced yields [62,65].

These findings underscore the importance of species selection, compatibility assessment, and appropriate management for successful grass–legume mixtures. Plant growth habit may serve as a useful basis for selecting compatible species [61]. The functional complementarity hypothesis suggests that selecting species with contrasting resource-acquisition strategies and growth forms can maximize complementary resource use while minimizing competition [66].

4.4. Nutritional Value Enhancement

The consistent improvement in nutritive value observed in grass–legume mixtures, including a 56–81% increase in crude protein (CP) and organic matter digestibility (OMD) of 52–59%, reinforces the dual benefits of these systems: increased biomass production and improved nutritive value. This is particularly important in dryland systems, where seasonal nutritional deficits can limit animal productivity [8]. The nutritional advantages are largely associated with the higher CP concentrations of legumes, which are generally three to four times greater than those of grasses (12–22% versus 2–11% of DM). In addition, nitrogen fixation by legumes increases the total nitrogen available within the system, while balanced grass–legume mixtures provide complementary energy and protein sources that support rumen function. The generally lower fibre fractions, including neutral detergent fibre (NDF) and acid detergent fibre (ADF), in mixtures can further improve forage digestibility.

For livestock producers, these improvements in forage quality have important practical implications, including potentially higher animal productivity through improved growth rates, milk yield, and reproductive performance, as well as reduced dependence on purchased concentrate feeds. Improved forage quality may also contribute to lower enteric methane emissions per unit of animal production. Tree legumes such as *Leucaena* and *Gliricidia* offer promise, with CP concentrations of 21–23% [51], providing high-protein supplements in hedgerow systems. However, their integration into dryland systems requires careful management to avoid negative interactions with herbaceous species.

4.5. Agroecological Context and Management Implications

Twenty-one studies (66%) provided adequate climate data to enable classification, while the remaining studies lacked sufficient information to adequately characterize their research contexts. The available data indicate that research has largely concentrated in areas experiencing severe land degradation, water scarcity, and fluctuating forage productivity, where 15–25% of semi-arid soils have been significantly degraded [67]. This concentration is appropriate given the substantial restoration needs in these environments; however, future research should also extend to less degraded areas to better understand preventative management strategies and the maintenance of ecosystem function before severe degradation occurs. Research across different aridity zones, including arid, semi-arid, and dry sub-humid environments, is also needed, alongside greater attention to climate change hotspots to inform the development of context-specific adaptive strategies.

A broader shift in drylands research is also warranted. Reynolds et al. [68] argued that global drylands research should move beyond a predominantly "desertification" narrative towards a forward-looking perspective centred on human livelihoods and ecosystem resilience. The findings of this review support this shift by highlighting the importance of active management approaches that can simultaneously enhance productivity and resilience. Such approaches should be tailored to local ecological and socio-economic conditions rather than relying on uniform interventions across dryland environments. Greater integration of traditional knowledge with scientific research is also needed to strengthen the relevance and applicability of restoration and forage-production interventions. Furthermore, participatory approaches that actively involve pastoral communities can help ensure that interventions reflect local priorities, knowledge, resource-use practices, and livelihood realities.

4.6. Knowledge Gaps and Research Priorities

Despite the demonstrated potential of grass–legume mixtures to improve forage productivity and nutritional value, the evidence base remains limited in several important respects. Only five studies included in this review were published since 2010, the range of species combinations was narrow, and most studies were based on researcher-managed experiments. These limitations constrain the generalisability of findings across the diverse dryland environments and production systems of Sub-Saharan Africa (SSA). To guide future research and support practical implementation, we prioritise the research needs according to their immediate relevance to mixture performance and adoption, followed by the need to broaden the evidence base and assess longer-term benefits.

Priority 1: Improve mixture establishment, persistence, and local adaptation. The immediate priority is to identify grass–legume combinations that establish successfully and persist under local environmental and management conditions. Poor legume establishment and persistence may constrain mixture performance because grasses can establish more rapidly and compete strongly with legumes. Grazing pressure, palatability differences, environmental stress, and management practices may further affect persistence. Future studies should therefore assess establishment rates, competitive interactions, and persistence over multiple seasons, including responses to grazing management, rather than relying solely on short-term biomass measurements. Testing locally adapted species and cultivars under the conditions in which they are intended to be used is also essential. This applied research can help identify practical combinations that maintain productivity and nutritional value while addressing establishment and persistence constraints.

Priority 2: Generate contemporary, locally relevant evidence through participatory on-farm trials. Only five studies in this review were published since 2010, limiting understanding of how grass–legume mixtures perform under current climatic, ecological, and socio-economic conditions. Climate change may alter species compatibility, compet-

itive interactions, productivity, and persistence, while changes in land use and livestock production may affect the feasibility of different management options. Research should therefore move beyond researcher-managed experiments to include participatory on-farm trials that reflect farmers' and pastoralists' management practices, resource constraints, and production objectives. Trials across arid, semi-arid, and dry sub-humid environments would help establish how mixture performance varies with rainfall, soil properties, and aridity. Where feasible, these studies should also evaluate performance under climatic variability and projected future conditions.

Priority 3: Identify suitable species combinations and address socio-economic barriers to implementation. Although 91 species were identified in the review, comprising 55 legumes and 36 grasses, the evidence was concentrated around a relatively small number of commonly studied species. Research should expand the range of species evaluated, particularly native and underutilised forage species with contrasting resource-acquisition strategies, drought tolerance, and adaptation to local conditions. Studies should determine whether greater species richness provides benefits beyond simpler grass–legume combinations and whether these benefits justify the additional seed, labour, and management requirements. At the same time, research should examine the factors that influence adoption and sustained use, including access to seed, labour, extension services, and livestock-management resources. Land tenure arrangements and historical land-management systems, including colonial legacies, may influence land access, grazing rights, and incentives to invest in restoring degraded or overgrazed rangelands. Gender and equity dimensions also require attention because access to forage resources, inputs, decision-making, and livestock-related benefits may differ among social groups. Integrating these factors into on-farm research would help identify interventions that are not only agronomically suitable but also socially and economically feasible.

Priority 4: Assess long-term productivity and wider ecosystem benefits. Longer-term and more integrated research is needed to determine whether the benefits of grass–legume mixtures persist beyond the short periods covered by most existing studies. Future research should assess mixture persistence and recovery following drought or grazing pressure, alongside longer-term changes in soil and ecosystem processes. Where resources permit, studies should integrate plant, soil, and livestock measurements to evaluate forage yield and nutritional value alongside soil fertility, soil carbon, livestock productivity, resource-use efficiency, and broader ecosystem services. Such integrated assessments would clarify the potential trade-offs and complementary benefits of grass–legume mixtures and strengthen evidence on their contribution to dryland restoration and production-system resilience.

4.7. Limitations

This review was restricted to peer-reviewed publications indexed in Web of Science and Scopus and published in English. Consequently, the relevant grey literature, technical reports, and studies published in other languages may have been excluded. In addition, despite extensive efforts to retrieve full texts through institutional subscriptions and publicly available repositories, 63 potentially relevant articles could not be accessed and were therefore excluded because their eligibility and data could not be verified. This may have introduced some selection bias, although the direction and magnitude of any resulting bias cannot be determined. Considerable heterogeneity among study designs, species combinations, experimental durations, management practices, and reported outcome variables also precluded a formal meta-analysis and limited direct quantitative comparisons across studies. The temporal distribution of the evidence represents another limitation. The studies included in the review spanned 1935–2026, meaning that some of the evidence was generated under environmental, agricultural, and livestock production conditions that

differ substantially from those currently prevailing in Sub-Saharan African drylands. Older studies may nevertheless provide useful evidence on species performance and mixture interactions, but their applicability to contemporary production systems and climate conditions may be limited.

Finally, only 32 studies met the inclusion criteria, highlighting the limited evidence base currently available on grass–legume mixtures for dryland forage production in Sub-Saharan Africa.

5. Conclusions

This review synthesised evidence from 32 studies on grass–legume mixtures in drylands of sub-Saharan Africa (SSA), addressing forage productivity, nutritional value, and species composition. Increased dry matter yield was reported in 85% of the studies that evaluated yield responses, with reported gains ranging from 13% to 500% relative to grass monocultures. The reviewed studies also generally reported improvements in forage nutritional value, including crude protein content. Across the included studies, 91 forage species were identified, comprising 55 legumes and 36 grasses, although evidence was concentrated on a relatively small number of frequently studied species.

The findings suggest that grass–legume mixtures can improve forage productivity and nutritional value, but the magnitude and consistency of these benefits vary among species combinations, environmental conditions, and management practices. The available evidence does not establish which environments are consistently suitable or unsuitable for these mixtures, nor does it support their uniform promotion across SSA drylands. Furthermore, forage yield and nutritional responses should not be interpreted as direct evidence of rangeland restoration, as restoration outcomes were not systematically measured in the reviewed studies. Interpretation is also constrained by the largely historical evidence base, limited representation of farmer-managed conditions, restricted searches to Web of Science and Scopus, and the inability to access more than half of the potentially relevant full texts. In addition, the heterogeneity of study designs and reported outcomes precluded meta-analysis, limiting the scope for estimating an overall effect across studies.

Overall, grass–legume mixtures warrant context-specific consideration as a forage production option rather than a universally effective intervention. Their practical suitability will depend on locally adapted species combinations, successful establishment and persistence, environmental conditions, and management requirements. Economic feasibility also remains uncertain because the available evidence does not adequately establish the costs of seed, labour, establishment, and ongoing management relative to the benefits obtained. Consequently, current findings support careful consideration of these mixtures for improving forage production and nutritional value, while stronger contemporary field evidence and economic assessments are needed before their wider benefits and scalability can be established.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/grasses5040048/s1, Table S1_PRISMA 2020 checklist; File S2_Extracted dataset from the 32 included studies; File S3_List of excluded studies and reasons for exclusion; and File S4_Study-Specific methodological assessment.

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Abbreviations

The following abbreviations are used in this manuscript:

ADF	Acid detergent fibre
ASAL	Arid and Semi-Arid Lands
CP	Crude protein
CPY	Crude protein yield
DM	Dry matter
GP	Gas production
IDRC	International Development Research Centre
KRSU	Karamoja Resilient Support Unit
ME	Metabolizable energy
MJ	Megajoule
NDF	Neutral detergent fibre
OM	Organic matter
OMD	Organic matter digestibility
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RECAF	Climate Resilient Animal Fund
SLU	Swedish University of Agricultural Sciences
SSA	Sub-Saharan Africa

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