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Grass-legume intercropping for sustainability animal production in the tropics

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Abstract

Seasonal and low forage availability and quality, shrinking of grassland area, and poor grassland management are the main causes of low soil fertility and animal production in tropical grasslands. One sustainable way to overcome the problems is through establishment of grass-legume intercropping in tropical grassland. Results revealed that grass-legume intercropping improved soil health and fertility, forage yield, and stability and reduced weed invasion. Besides, it improves forage nutritive value and animal production. To enhance grass-legume intercropping, the selected grass and legume species should be matched with local environmental conditions followed by good management.

Keywords: animal production, forage yield and quality, grass-legume intercropping, soil fertility

Review Methodology: Recently published literature in Google Scholar, CAB Abstracts, Scopus, PubMed, Cross Ref and Web of Science were retrieved using keywords of grass–legume intercropping, animal production forage yield and quality, and soil fertility from April 2019 to September 2020. We also used synonym and antonym of those keywords for searching relevant literature. Of about 200 articles read, 93 were selected for review.

Introduction

The major problem faced by livestock keepers in the tropics is how to provide adequate feed, both quantity and quality for their animals throughout the year. In the tropics, there is a wide fluctuation in forage supply as affected by the season. During the wet season, dry matter yield and quality of natural grasses that comprise most forage resources are quite high; however, during the dry season, their yield and quality are very low, and consequently, growth of animals grazing on natural grassland is generally also low, which leads to longer time for the animals to reach market weight, poor reproductive performance, and low resistance to infectious diseases.

In many densely populated countries like Indonesia, the low availability of forage is aggravated by shrinking of grassland areas. Due to high human population density and economic growth, the farmers tend to convert grassland area to food and plantation crops, housing, and industrial uses. In recent years, poor management of the remaining grassland aggravates availability of forages. Driven by high demands for beef, the farmers tend to raise the animals in grassland with high stocking rates throughout the year. Consequently, during the dry season, most grasslands are undergoing overgrazing, which leads to a loss of soil cover and increased soil compaction, which impairs water infiltration and accelerates soil and wind erosion. Soil degradation and deficiency of soil nutrients, especially N and other nutrients, lead to reduced forage productivity, biological diversity, and carrying capacity and increased weed invasion [1]. About 20% of worldwide pasture and 73% of rangelands in dry land areas have been degraded [2]. Mugerwa *et al.* [3] noted that soil macronutrients (N, P, and K) in overgrazed grasslands are usually below the critical levels required to support establishment and growth of high-yielding and palatable forages such as *Brachiaria* and *Panicum* species. Increased soil degradation of tropical grassland is an important cause of lower animal production from tropical grassland compared with temperate grassland [4]. Animal production from tropical grassland is generally low, only up to 75 kg live-weight gain/ha per year in some environments and up to 120 kg LW gain/ha per year in mixed crop-livestock systems [5].Only in limited cases have high weight gain (1000–1500 kg LW gain/ha per year) been reported, as in some specialized systems, for example, irrigated *Leucaena leucocephala*—grass pasture [6].

One way to improve soil fertility of tropical grassland is through application of inorganic fertilizers. However, this practice is uneconomic under most tropical conditions, and excessive N-inorganic fertilizer use can lead to environmental pollution and increased global warming [7]. Grass-legume intercropping is a suitable way to prevent soil erosion and land degradation because fibrous root of grass can increase soil porosity and water-holding capacity, while tap roots of legumes such as *L. leucocephala* can provide superficial and deep-seated soil erosion control [8]. N and P are the most commonly deficient nutrients in tropical grassland [9] and the use of legumes is a more sustainable strategy to increase soil fertility and productivity of grassland because legumes have the ability to fix atmospheric N_2 that can improve soil fertility, growth, and quality of companion grass at low cost [10].

Grass-legume intercropping has been widely used to improve soil fertility and animal production in temperate grassland, but in the tropics, establishing of C_4 tropical grasses intercropped with legumes is more difficult because of slower growth rates of legumes and aggressiveness of C_4 grasses [11, 12]. This paper aims to review literature concerning the effects of grass-legume intercropping on soil fertility, forage yield, nutritive value, and animal production from tropical grassland and how to establish and maintain a high proportion of legumes in tropical grassland.

Advantages of grass-legume intercropping

Under fertile soil conditions, monoculture of highly productive grass generally produces higher yields when it is N fertilized [13]; however, in nutrient-poor grassland, dry matter yield of grass-legume mixture is generally higher compared with N-fertilized grass monoculture [14]. Table 1 presents the benefits of grass-legume intercropping in a grassland ecosystem.

The grass-legume mixture improved soil heath (Table 1). Healthy soil can increase forage yield and quality with minimum cost. Managing for healthy soil is mostly achieved by providing good habitats for soil microorganism. This can be conducted by practicing tillage conservation and increasing biodiversity [29]. Increasing soil carbon and nitrogen storage by growing grass-legume mixture also increases the number of microorganisms in the soil [15]. Further, because of the acquisition of nitrogen as diatomic N by legume, pH of soil becomes lower and this promotes plant-soil-microbial activity [30].

Inorganic and organic fertilization increases nitrous oxide gas emission, but grass-legume mixture increased productivity but did not affect N_2O emission (Table 1). This might be due to the fact that mineralized N is rapidly taken up by the grass that reduces available N for denitrification [31].

Biomass production of grass-legume mixture has a greater stability than monoculture (Table 1), because it exhibits more even seasonal growth distribution than grass monoculture. Grass-legume mixture is more adaptable to changing climatic conditions than monoculture, because deep roots of legumes can compensate for slower growth of grass during the dry season. One study compared monoculture of four annual species, and five intercropping treatments of those species reported that intercropped species had similar yields to highest-producing grass monoculture but had greater yield stability [32]. Further, grass-legume mixture can reduce risk in cropping system because each plant species may respond differently to soil, pest, and weather conditions. Even in less-productive agriculture, grass-legume intercropping can contribute significantly to more sustainable agriculture [33].

Grass-legume intercropping also can prevent or reduce soil erosion (Table 1). Grass is the best choice against soil erosion because its extensive root system can protect and rebuild the soil, but in soil rehabilitation, grass-legume mixtures are better than grass or legume monoculture owing to the ability of legumes to supply N to the soil and the grass can prevent the soil heaving characteristic of some herbaceous legumes when grown in monoculture [34]. A mixture of fast-growing grasses and slow-growing legumes generally provides better erosion and weed control owing to more ground being covered by vegetation and the upper plant leaves intercept more raindrop before they dislodge soil particles [35]. Grass-legume mixture could reduce erosion by 20%–30%, reducing leaching of nitrogen and carbon losses, and enhancing carbon sequestration [36].

Weeds growing in grassland can reduce forage yield (Table 1) because they compete with forage for the same resources. A high proportion of weeds can reduce yield and nutritional value of forage. Planting mixture of grasses and legumes can create a highly competitive environment that can be an effective means to suppress weeds [19, 37], while disturbance of vegetation such as land clearing, burning, and overgrazing may enhance invasion of weeds such as *Chromolaena odorata* [38] and *Lantana camara* [39]. The efficacy of a mixture of grass and legume in controlling weed differs, depending on the species constituting the mixture. A mixture of *M. maximus* and *Stylosanthes seabrana* was more effective in controlling weeds than a mixture of *M. maximus* and other legumes such as *M. atropurpureum*, *C. ternatea*, and *S. hamata* [40], probably because the mixture of *M. maximus–S. seabrana* produces a denser foliar biomass than the latter mixture.

Grass-legume mixtures improved soil fertility (Table 1), mostly due to the presence of the legume, which adds N

Table 1. Effect of grass-legume intercropping on soil conditions, weed control, forage yield, and quality.

	Grass-legumes mixture	Effects	Author
	Improved soil health and fertility, weed control, and reduced soil losses		
1	*Bromus biebersteinii, Dactylis glomerata* versus *Medicago sativa*	Improved mineralizable soil C and N and total microbial biomass in soil.	[15]
2	*Glycine, Siratro, Dolichos*, Velvet bean, and Stylo introduced into natural pastures	Introduction of legumes increased soil pH (4.9–5.4), organic carbon (1.17%–2.57%), nitrogen (0.17%–1.22%), and potassium (1.23–1.68 me%) over natural pastures.	[16]
3	Mixture of *Agrostis capillaris—T. pratense* compared with N-fertilized grass or legume monoculture	Inclusion of legume in grass-legume mixtures increased productivity but had no effect on N_20 emission.	[17]
4	Hedges of solo *P. purpureum*, *C. calothyrsus*, and intercrop hedge of *C. calothyrsus–P. purpureum*	Intercrop hedge reduced soil losses (7.4 Mg/ha) compared with sole *P. purpureum* (11.2 Mg/ha) and control (10.9 g/ha).	[18]
5	*Zea mays* monoculture versus Zea mays mixed with *Cicer arietinum, Pisum sativum, Arachis hypogaea, or Lens esculenta*	*Zea mays* monoculture had the highest weed density.	[19]
	Forage yield, stability, and nutritive value		
6	Sole *Brachiaria* sp. versus intercrop of *Brachiaria* sp. and *Arachis pintoi*	DM yield was 9.3% higher in intercrops than sole *Brachiaria* sp..	[20]
7	*P. glaucum*, *S. bicolor* (grasses) versus *Vigna unguiculata, Crotalaria juncea* (legumes)	Mixture of grasses and legumes showed more yield stability than grasses or legumes monoculture.	[21]
8	Solo *P. purpureum* versus *Stylosanthes scabra*, cv. Seca versus *M. atropurpureum* cv. Siratro–*P. purpureum* mixture	DM yields, CP contents, and DM degradability of mixtures were higher than those of sole Napier grass.	[22]
9	*Brachiaria decumbens* versus *B. decumbens–A. pintoi* mixture	Intercrops increased forage yield by 33%, crude protein by 30%, and digestibility by 2.2% over sole *B. decumbens.*	[23]
10	Sole *Megathyrsus maximus* versus *M. maximus–Lablab purpureus* mixture	DM yields and CP content were higher in intercrops but NDF and ADF were lower than those for sole *M. maximus.*	[24]
11	Sole *M. maximus* versus *M. maximus* mixed with *S. guianensis* or *C. pubescens*, or *A. pintoi* or *Macroptilium bracteatum* mixture	Dry matter yields of intercrops were higher than those of sole *M. maximus.*	[25]
12	Sole *P. purpureum* versus *P. purpureum–Desmodium intortum* or *Lablab purpureus*	CP yield, CP, and ADL OM digestibility were higher in intercrops than those in sole *P. purpureum.*	[26]
13	Sole *M. maximus* versus mixture of *M. maximus* and *S. guianensis*, or *Aeschynomene histrix*	DM yield, CP, DM and CP degradability, phosphorus, calcium, sodium, and iron content were higher in intercrops than those in sole *M. maximus.*	[27]
14	*P. purpureum* mixed with *D. intortum* or *M. axillare* or *N. wightii* and harvested at 8- and 16-week interval	*P. purpureum–D. intortum* mixture gave higher yield than two other mixtures. As increasing cutting interval, CP contents of intercrops decreased but NDF and ADF contents increased.	[28]

to the soil system through biological N-fixation and recycling P and K by absorbing those nutrients from the lower strata of soil and returning them to the soil surface. The amounts of N fixed in legume-grass pastures ranged from 13 to 682 kg N ha^{-1} yr^{-1} [41] that can improve N soil content and yields of neighboring plants. N fixed can be transferred to other plants through direct transfer, return in animal excreta, or decomposition of decayed legume plant parts in the soil [42], but most fixed N is added to soil ecosystems mainly through decomposition of legume plant parts and via excreta from grazing animals [43]. In Kenya, introduction of legumes (mainly Glycine, Siratro, and Stylo) into natural grassland had been reported to increase N and K contents of soil [16], while in Brazil, Cadisch *et al*. [44] also reported a positive soil N balance from *B. decumbens—C. mucunoides* mixture compared with pure *B. decumbens* pasture.

Grass-legume mixture generally exhibits greater dry matter yield than grass or legume monoculture (Table 1). There are several causative factors for this, but mostly it is attributed to the increased N supply from legume to the soil and the more efficient use of resources.

In grass-legume intercropping, sunlight is used more efficiently because light that passes through tall plants is captured by low-growing plants that lead to higher net photosynthesis [35]. Differences in rooting depth between grasses and legumes in mixture may result in better resource exploitation through niche differentiation [45]. Grass-legume intercropping also improves water use efficiency as more soil cover prevents evaporation losses, and their roots with varying lengths are able to extract moisture from different layer of soil [46].

Grass-legume mixture also improves the nutritive value of forage (Table 1). Compared with legume species, grass has lower nutritive value. Grass has higher NDF and ADF and lower crude protein, digestibility, and relative feed quality than do legume species [47]. The main disadvantages of forage legumes compared with grass are lower persistence under most grazing conditions, high risk of bloat, and difficulty in conserving as silage or hay [48].

Like temperate forages [15], the mixture of tropical grass-legume affects their nutritive value. In general, as high crude protein of legume and high fiber contents of grass, crude protein of grass-legume mixture is higher and NDF and ADF contents are lower than grass monoculture. Crude protein yield is also affected by grass legume intercropping. As higher dry matter yield of intercrop, crude protein yield of intercrops is generally higher than solo grass or solo legume. In sorghum-soybean intercropping, crude protein yield in intercrops increased by 25 g kg^{-1} compared to solo soybean [49].

Besides increasing crude protein and reducing NDF and ADF, intercropping also increased digestibility [50, 51] and nutrient degradability [27, 52]. The increased digestibility and degradability of intercrops might cause lower their NDF ADF contents because of low ADF contents because with lower ADF values, digestibility increases.

Animal performance

Animals gazing on a mixture of grass-legume showed improvement of performance compared to those grazing on grass monoculture (Table 2).

By grazing animals on grass-legume pastures, significant improvement in animal production was obtained (Table 2). This might be due to the higher feed intake, crude protein, digestibility, and degradability and the lower NDF and ADF contents of grass-legume mixture compared with grass monoculture.

Besides, grass-legume mixtures can supply a more balanced energy-protein mix to the animals because legumes can supply sufficient crude protein for grazing animals and grasses can supply more energy to sustain weight gains with much lower external energy expenditure and greenhouse gas emission than fertilized grass pasture. Legume forages–fed ruminants generally emitted less methane than grass-fed animals per unit of feed intake. The presence of secondary metabolites in some legume species, such as condensed tannins, may be useful for reducing greenhouse gases, because several studies have proved that condensed tannins in the diets [60] reduced methane production and protein digestion [60, 61]. Natural tannin in certain legumes can decrease protein degradation in the rumen and N urinary excretion by ruminants and may lead to increased flux of bypass protein for absorption in the small intestine [62]. A mixture of *Phleum pratense* with tanniferous legume of *M. sativa* also has been reported to increase nonstructural carbohydrates content of forages [63] that potentially result in more efficient use of N by ruminants.

Enhancement of grass-legume mixture in the tropics

Tropical grasses generally have higher competitive ability over legumes, and therefore grass tends to dominate tropical grassland but to maintain a high animal production, a good balance between grass and legume is desirable. A study

Table 2. Performance of animals grazing on mixture of grass-legume and monoculture.

No.	Treatments	Results	Author
1	Animals grazed on *L. leucocephala–M. maximus* mixture versus grazed on *M. maximus* monoculture	Animals grazing on intercrops had greater DM intake than those grazed on *M. maximus* (26.1 vs. 20.4 g/kg of BW/d) and greater crude protein intake (954 vs. 499 g/day).	[53]
2	Cows grazed on mixture of *B. decumbens–L. leucocephala* versus grazed on *B. decumbens* monoculture	Cows grazed on intercrops produced higher milk yield (10.4 liters/day) than those grazed on pure *B. decumbens* (9.5 liters/day).	[54]
3	Sheep grazed on *M. maximus—L. leucocephala* and grazed on *M maximus—G. sepium* pasture	Daily gain of sheep grazed on mixture of *M. maximus* with *L. leucocephala* and *G. sepium* was 20.3 and 20.1 g/day, respectively.	[55]
4	Cattle grazed on *B. brizantha–A. pintoi* versus grazed on *B. brizantha* monoculture added with 120 N/ha/yr	Mixed pasture produced greater cattle production (789 kg/ha/yr) compared to the fertilized grass monoculture (655 kg/ha/yr).	[56]
5	Cattle grazed on *B. brizantha* mixed with *S. guianensis* versus grazed on pure *B. brizantha*	Daily gain in mixed pasture was higher (0.44 kg/head/d) than that in solo grass (0.35 kg/head/d).	[57]
6	Steers grazed on a mixture of buffel grass and *L. leucocephala* compared with those grazed on buffel grass monoculture	Steer grazed on mixed pasture gained 250–300 kg/head while those grazed on buffel grass monoculture gained 140–150 kg/head.	[58]
7	Cattle grazed on dwarf elephant grass mixed with peanut versus those grazed on dwarf elephant grass added with 150 kg N/ha	Cattle grazed on a mixture of dwarf elephant grass and peanut gained 0.97 kg/d, while those grazed on fertilized grass gained 0.70 kg/d.	[59]

in temperate region indicates that 30%–50% legumes to be an optimal proportion because it produced the highest total forage yield with the highest quality [45]. In several areas of the tropics, the same proportion is also recommended. A study in Pakistan revealed that a combination of *V. sativa* plus *V. unguiculata* 33% intercropped with *M. maximus* 67% was the best ratio [64], while in Malaysia, a mixture of guinea grass–*C. pubescens* with the proportion 50%:50% was the most compatible combination [25].

In tropical grasslands, to achieve a good balance of grass and legume, the management of grass-legume mixture is more complicated and maintenance of a high proportion of legume is difficult. This is attributed to the higher rates of photosynthetic and growth rates of C_4 tropical grasses compared with C_3 legume plants [65]. Therefore, to maintain a high proportion of legume that will be mixed with tropical grass, grasses and legumes should be carefully selected, planted, and followed by good management.

Many factors should be considered when making a species selection. Selected species or variety should be adapted to the soil, acclimatized to the regions, and matched to the intended use of pasture. Increasing forage yield and stability can be achieved by planting two or more forage species that are well matched to the environmental conditions. The more complementarity of species comprising the mixture, the more likely that the mixtures will outproduce monocultures [66].

Many tropical grasses have been selected for high yield and vigor in monoculture with N fertilization. Considering the importance of high legume content in grassland, the selected legumes should be mixed with low-yield vigorous grasses. The selection for high-yielding grasses is less important in grass-legume mixture because it is unlikely the legume can supply sufficient N to meet N requirement of high-productive grasses [67].

Competition between grass and legume can be mitigated by selecting legumes that are compatible with grasses. In general, climbing or shrubby legumes such as *Centrosema* spp. and *Pueraria* are most suitable to be mixed with tall grasses such as *M. maximus*, and low-growing stoloniferous rhizomatous legumes such as *A. pintoi and Stylosanthes* spp. are most suitable for mixing with spread grasses such as *Brachiaria* sp. Shade tolerant legumes such as *A. pintoi* can persist under tall grass such as *M. maximus* because of its high phenotypic plasticity, which enable it to exploit the spatial heterogeneity of the pasture efficiently [59].

Legume plants can fix N_2 if they have good functioning nodules. To achieve an effective symbiotic N-fixing relationship, the selected legume should be matched with sufficient quantity of compatible *Rhizobium* bacteria. There are numerous strains of native rhizobia in the soils, but they vary in their efficiency to fix nitrogen and they are often less effective in nitrogen fixation. If the legume species has not grown long in the field, inoculation of legume seeds prior to sowing is recommended [68]. Legumes can supply almost all of their N requirement from N they fixed, provided they are inoculated with the proper strain of *Rhizobia* [51], but they can also take up large quantities of soil N if it is available [69].

Fertilization affects competition between grasses and legumes in mixture. As grass and legume have different nutrient requirements, the application of fertilizers needs to be carefully considered. Excessive application of N reduced nodulation and N fixed by legumes [70] due to the low supply of photosynthates to nodules [71]. However, a certain level of N is needed in early legume development in order to overcome N deficiency during early symbiotic N fixation [72], but N fertilizer rates exceeding "starter N" generally reduce nodulation and N fixation [73]. For greatest N-use efficiency and sustainable legume production in grass-legume mixture, using a moderate amount of N fertilizer (75 kg N ha^{-1}) is recommended to provide optimum benefits [74].

Besides N, phosphorus (P) is one of several nutrients that affect nodulation and N fixation. Highly weathered soils in the tropics generally deficient in P. Nodules are strong sink for P assimilation, and as a consequence, legume plants require more P than those supplied with combined N [75]. Legumes need more P for energy transformation. Highly weathered tropical soils that are found in many humid tropical soils with pH less than 4 are generally low in phosphorus [76]. Deficiency of P restricts nodule growth, photosynthesis, translocation of sugar, and other functions that influence N fixation [77]. The lack of P might contribute to the low-competitive ability of legumes in tropical grassland.

Many legumes can tolerate a wide range of soil pH, but they are most productive when soil pH is near 7.0. Liming should be conducted when soil pH values fall below 6.0. Soil liming helps to reduce the amount of toxic form of Al, Fe, and Mn and increase the amount of readily available P in the soil [78].

The management of grass-legume mixtures is complicated further by the preference of animals for certain forage species. Pen feeding studies with *Danthonia decumbens* demonstrated a preference of *D. decumbens* over siratro by animals in certain season. In spring and early summer, only a small proportion of siratro (2%–10%) was selected by animals, but in autumn, siratro constituted a major part of the diet (62%–73%) [79]. Selective grazing can lead to a reduction of preferred species, although grazing pressure may be low. Therefore, it is better not to include very palatable legume species into the grass-legume mixture system.

Species and morphology of forages constituting the mixture affect their preference by cattle. In general, as stocking rates increase, legume contents will decline because of their slow regrowth ability [65]. Erect growth legume like *S. guianensis* and twining growth legumes such as siratro and *D. intortum* are sensitive to severe defoliation, given their longer recovery phase after defoliation, but the prostrate legumes like *L. bainesii* and *D. heterophyllum* are more tolerant to heavy grazing [67], because they can escape close grazing. Leaves of low-growing legumes such as *S. humilis* can receive sufficient light if taller companion grasses are removed by heavy defoliation, and leaves of twining legume such as siratro can be displayed in sunlight if grazing pressure is lenient to permit the legumes to climb the companion grasses [11].

Cutting interval affects dry matter yield of grass-legume mixtures. By increasing cutting interval from 20 to 30 and 40 days, dry matter yield of grasses of *B. ruziziensis*, dwarf Napier grass, and Taiwan A25 intercropped with *L. leucocephala* increased, but *L. leucocephala* yield was unaffected. Less-frequent cutting increased total dry matter yields in all combinations [80].

Increasing cutting interval from 8 to 16 weeks on several tropical legumes–Napier grass mixture increased total DM from 28 to 35 tons/ha [28]. Increasing stocking rate in tropical grass–herbaceous legume pastures was usually followed by a reduction of legume components, particularly those having twining growth habit [81]. High stocking rates might be the important reason why it is very difficult to maintain a high proportion of herbaceous legume in the tropical grassland.

Taking into consideration the difficulty to maintain high proportions of herbaceous legumes in pastures, the use of tree legume species that have a high survival mechanism may be a good solution to increase competitive ability of legumes in tropical grassland [82]. In *L. leucocephala*-Rhodes grass mixture, Rhodes grass in the upper 1.5 m soil profile had a root abundance 8–10 times greater than *L. leucocephala*, which allows the grass to compete more effectively for water resources than *L. leucocephala*. However, this advantage was negligible at the highest *L. leucocephala* density owing to the reduced grass growth by shading and increased water uptake by *L. leucocephala*, especially during the dry season [83].

Lessons learned from grass-legume intercropping in the tropics

In the tropics, natural grasslands are the main source of forage for livestock throughout the year. The low yield and quality of forage growing in the grasslands, especially during the dry season, are the main causes of low productivity of animals raised in tropical grassland. Establishing legumes in the grassland might be the best method to increase animal production from tropical grassland; however, low persistence of legumes has been reported to be a limiting factor for successful introduction of legumes into tropical grassland.

There are many factors contributing to the low persistence of legumes in tropical grassland, but the important factors are species comprising the pasture and the management system imposed. In general, intercropping herbaceous legumes with grasses was not persistent in grassland. This is attributed to the shorter root system and lower height of herbaceous legume compared to tree legumes, which leads to slower growth rates during the dry season and reduced regrowth when they are shaded by taller grasses or overgrazed. By contrast, after establishment, tree legumes have higher competitive ability for light, water, and nutrients compared with herbaceous legumes [84], which lead to higher biomass yield and amounts of nitrogen fixed. In the tropics, the number of tree legumes species used for improving soil fertility and animal production is still limited compared to the large number of species present, and this needs to be studied in order to achieve high and sustainable animal production.

Conclusion

1. Grass-legume mixtures have a higher potential to lower soil degradation and weed invasion and improve soil fertility.
2. Grass-legume mixtures have higher nutritive value, digestibility, degradability, and animal production potential than monoculture.
3. Forage tree legumes are recommended to be established in tropical grassland to obtain high forage yield and sustainability.
4. To maintain a good proportion of grass-legume mixture, species for mixture should be selected carefully followed by proper management.

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