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Agro-Ecological Assessment of Forage and Fodder Species Diversity in Nepal

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ABSTRACT

Livestock production suffers from a seasonal feed imbalance, with an abundance of green forage during the monsoon and a scarcity in the spring and winter in Nepal. Utilizing a wide range of fodder crops is essential to overcoming this obstacle. Approximately 275 cultivated plant species have been identified as forage species in Nepal, out of the approximately 510 forage species that are readily available. Furthermore, Nepal has more than 500 species of fodder trees. Approximately 250 tree species are regarded as economically important fodder trees among them. Due to their greater biomass, palatability, and adaptability, farmers in the Terai and mid-hill regions grow both native and introduced grass species, such as fodder oats (*Avena sativa*) and Napier grass (*Pennisetum purpureum*). Certain pasture grasses, like timothy, Setaria, and ryegrass (*Lolium spp*.), are planted in higher, colder climates. Because of their increased protein content and ability to fix nitrogen biologically, leguminous forages such as vetch, joint vetch, and forage peanut are being encouraged more and more. Certain fodder tree and shrub species, such as *Premna integrifolia* (Ginderi), *Ficus semicordata* (Khanayu or Nebharo), and *Artocarpus lakoocha* (Khanyu), are thought to be essential to traditional cattle farming and agroforestry systems. The diversity, distribution pattern, and seasonal availability of Nepalese forage and fodder species are examined in this review paper, with an emphasis on their potential for genetic improvement. Utilizing diverse fodder and forage species guarantees year-round feed availability in Nepal's various agro-ecological zones.

Keywords: Forage crops, fodder trees, genetic resources, livestock, legumes

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INTRODUCTION

Raising livestock provides food, cash, and a means of livelihood for millions of smallholder farmers in Nepal. This sector greatly contributes to the production of milk, meat, draught power, and manure, and it is a crucial component of mixed crop livestock production systems. Feed scarcity limits livestock productivity despite its importance, especially in the winter and spring. Their productivity, growth rate, and reproduction have all decreased as a result, leading to a rise in the use of commercially compounded feeds (Sharma 2015, MoALD 2020). Livestock production in Nepal is impacted by a seasonal feed imbalance. Green fodder is plentiful during the monsoon but sparse in the spring and winter. Utilizing the genetic diversity of fodder crops is crucial to solving this problem. Out of 510 forage species, approximately 275 cultivated plant species are classified as forage species in Nepal. Furthermore, there are about 500 different species of fodder trees in Nepal. Among these, more than 250 tree species are considered valuable fodder trees (Upreti and Devkota 2017).

A vast diversity of forage and fodder species, including grasses, legumes, shrubs, and trees, are supported by Nepal's diverse geography, which stretches from the high Himalayas to the Terai plains. High-yielding species like Napier grass (*Pennisetum purpureum*) and fodder oats (*Avena sativa*) are common in Terai and mid-hills, while temperate species like timothy (*Phleum pratense*) and ryegrass (*Lolium* spp.) are more common in high-hill pastures (Devkota et al 2015). Leguminous forages increase soil fertility and protein content through biological nitrogen fixation, while fodder trees improve feed during dry periods. Since genetic diversity the basis for species' capacity to adapt to environmental pressures, conservation and usage are essential for boosting biomass, nutritional value, and animal resilience under climate variability (Behera et al 2024). However, many of these species are underutilized, and little is known about their genetic makeup, distribution, and seasonal availability. This review offers recommendations for breeding, conservation, and sustainable feed management while integrating the diversity, spatial patterns, and functional roles of Nepalese forage and fodder species. It also identifies research needs and opportunities.

Agro-Ecological Zones and Forage Distribution

Nepal's agro-ecological zones the Terai, mid-hills, and high Himalayas have a major impact on forage availability, species composition, and production. Terai region (≈ 60–1000 m asl): The subtropical climate and fertile soils, which contain both cultivated species like *Avena sativa, Trifolium alexandrinum*, and *Vicia spp.* and perennial grasses like *Pennisetum purpureum* and *Stylosanthes guianensis*, sustain high fodder production. Although stall feeding is common, there are still significant production gaps during periods of difficulty (Sharma 2018, Dhakal 2021). Mid-hills (between 1000 and 2000 meters above sea level): Among the naturally occurring grasses, legumes, and tree fodders that flourish in temperate regions with terrain are *Ficus semicordata, Artocarpus lakoocha, Buddleja asiatica*, and *Castanopsis tribuloides*. Grasses including *Imperata cylindrica, Saccharum spp*., and *Setaria spp*. are important in communal grazing. Yaks, sheep, and goats graze on cold-tolerant grasses, shrubs, and native legumes in high hills and mountainous areas (> 2000 m asl), while fodder trees and high-altitude legumes supply vital winter feed. These zonal variances underscore the need for region-specific feed management strategies to optimize cattle productivity and nutrition.

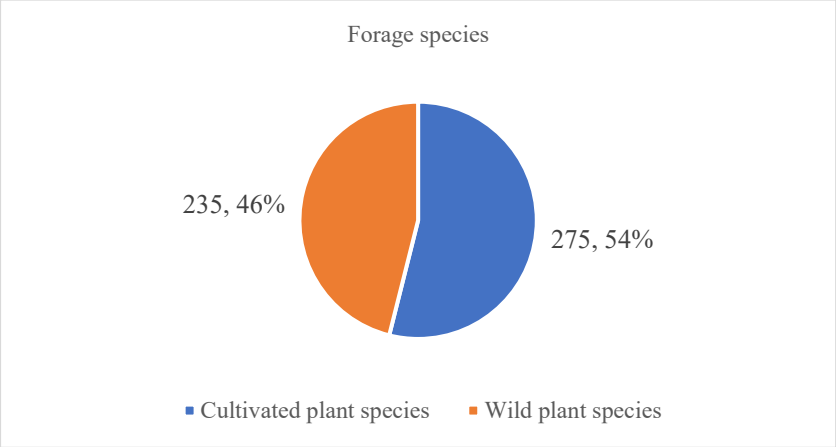

Fig. 1. Number of different forage species found in Nepal (Adapted from Joshi et al 2020)

Nepal has a wide variety of forage species (510) from both cultivated and wild sources, with 275 cultivated plant species and 235 wild plant species used as fodder (Fig. 1). The somewhat increasing number of planted forage species reflects increased farmer adoption, domestication, and promotion of improved forage crops to meet livestock feed needs, particularly in mixed crop–livestock systems.

Diversity of Forage Species

Grass Forages

Particularly during the monsoon and post-monsoon seasons, grass forages (family Poaceae) make up the majority of ruminant diets. Seasonal availability and feeding habits are influenced by the growth habits of various species, including annual and perennial. Timothy (*Phleum pratense*), cocksfoot (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), Napier grass (*Pennisetum purpureum*), and *Setaria spp*. are common grasses that thrive in temperate to subtropical regions. Under cut-and-carry systems, better cultivars boost biomass yield and year-round availability in the Terai, Inner Terai, and hill regions (Rai 2024). Other advantages of well-managed grasses include soil protection and rangeland biodiversity (Rai 2024, Ghimire et al 2021). While grasses provide bulk fiber, legumes and fodder trees are often required to supply the protein needs of high-yielding livestock.

Table 1. Growth habit, agro-econlogical zone and seasonal availability of forage grass species found in Nepal

SN	English name	Nepali name	Scientific name	Growth habit	Primary agro-ecological zone	Seasonal accessibility
1	Oat	Jai	*Avena sativa* L.	Annual grass	Mid-hills, High-hills	Winter–Spring (Dec–Apr)
2	Sacrificial grass	Kush	*Desmostachys bipinnata* (L.) Stapf	Perennial grass	Terai, Siwalik	Year-round (peak in monsoon)
3	Siru	Siru	*Imperata cylindrica*	Perennial grass	Terai, Siwalik	Monsoon–Post-monsoon
4	Kans	Kans	*Saccharum spontaneum*	Perennial grass	Terai, Siwalik	Monsoon–Post-monsoon
5	Thatch grass	Kaans	*Saccharum spontaneum* L.	Perennial grass	Terai, Siwalik	Monsoon–Post-monsoon
6	Bermuda	Dubo	*Cynodon dactylon*	Perennial grass	Terai, Mid-hills	Year-round (peak

SN	English name	Nepali name	Scientific name	Growth habit	Primary agro-ecological zone	Seasonal accessibility
	grass		(L.)			in monsoon)
7	Broom grass	Amrisho	*Thysanolaena maxima*	Perennial grass	Mid-hills	Monsoon–Post-monsoon
8	Napier grass	Seto Kans / Napier	*Cenchrus purpureus* (syn. *Pennisetum purpureum*)	Perennial grass	Terai, Mid-hills	Year-round (peak in monsoon)
9	Foxtail millet	Kaaguno	*Setaria italica*	Annual grass	Mid-hills, High-hills	Summer–Autumn (Jul–Oct)
10	Ryegrass	Ryegrass	*Lolium multiflorum* / *L. perenne*	Annual/Perennial grass	Mid-hills, High-hills	Winter–Spring (Dec–Apr)
11	Timothy grass	Timothy	*Phleum pratense* L.	Perennial grass	High-hills, Cool Mid-hills	Spring–Early summer (Mar–Jun)

(Adapted from DLS 2022, Dhakal et al 2021, MOALD 2023, Shrestha et al 2018)

The diversity of Nepal's forage grass species in terms of growth habit, agro-ecological distribution, and seasonal availability is shown in Table 1, allowing for a year-round supply of fodder across the nation. There are both annual (like oat, foxtail millet, and ryegrass) and perennial (like dubo, napier, kans, and siru) grasses, but perennials are more common, ensuring long-term feed availability. The Terai and Siwalik zones are particularly rich in perennial grasses, such as *Saccharum spontaneum, Imperata cylindrica*, and *Desmostachys bipinnata*, which are most numerous during the monsoon and post- monsoon seasons. On the other hand, cool-season annuals and temperate perennials like timothy, oats, and ryegrass, which supply food from winter to spring and spring to early summer, are primarily responsible for the Mid-hills and High-hills. Species like Napier and Bermuda grass, whose growth peaks during the monsoon, offer year-round availability, highlighting their need for continuous feeding. Overall, the graph illustrates how Nepalese livestock systems can deliberately use grasses that are suited to different zones and seasons to close seasonal feed gaps and offer a year-round supply of fodder.

Leguminous Forages

Leguminous forages (family Fabaceae) are high in crude protein (CP) because they fix nitrogen. They improve soil fertility and provide nutrient-dense feed, which is crucial during the winter months when grass biomass declines. In the hills and Terai, short-duration farmed legumes such as berseem, shaftal, common vetch (*Vicia sativa*), and Egyptian clover (*Trifolium alexandrinum*) are planted for winter or dual-season production. Perennial legumes like Stylosanthes, Desmodium, and Centrosema are used to increase biomass and quality on terraces or mixed pastures. Agroforestry systems incorporate fodder shrubs and small trees such as *Leucaena leucocephala* and *Flemingia macrophylla* (Ghimire et al 2021). Legumes encourage multi-cut systems for year-round feed delivery, increase digestibility, and reduce the demand for concentrate feeds.

Table 2. Growth habit, agro-econlogical zone and seasonal availability of forage and fodder legume species found in Nepal

SN	English name	Nepali Name	Scientific name	Growth habit	Agro-Ecological Zone	Seasonal availability
1	Berseem clover	Berseem	*Trifolium alexandrinum*	Annual legume	Terai, Mid-hills	Winter (Nov–Mar)
2	Leucaena, Subabul	Ipil-ipil	*Leucaena leucocephala*	Shrub / tree legume	Terai, Mid-hills	Year-round (peak in monsoon & post-monsoon)
3	Common vetch	Ankure koseli / Vetch	*Vicia sativa*	Annual legume	Terai, Hills	Winter–spring (Dec–Apr)
4	Stylo	Stylo	*Stylosanthes* spp.	Perennial legume	Mid-hills, Terai	Summer–autumn (Jun–Oct)
5	Desmodium	Desmodium / Ban bodi	*Desmodium* spp.	Perennial legume	Mid-hills	Spring–autumn (Mar–Oct)
6	Red clover	Rato clover	*Trifolium pratense*	Perennial legume	Mid-hills, High hills	Spring–summer (Mar–Jul)
7	White clover	Seto clover	*Trifolium repens*	Perennial legume	Mid-hills, High hills	Spring–autumn (Mar–Oct)

(Adapted from Joshi et al 2020, DLS 2022, Dhakal et al 2021, MOALD 2023, Shrestha et al 2018)

Table 2 illustrates the variety of forage and fodder legume species in Nepal with respect to growth habit, agro-ecological distribution, and seasonal availability, highlighting their complementary roles in supplying year-round feed for livestock. The species include annual legumes like berseem clover and common vetch, which are mostly available from winter to spring and are essential for filling fodder gaps in the dry season, as well as perennial legumes like Stylosanthes, Desmodium, red clover, and white clover, which provide longer forage availability from spring through autumn.

The Terai and Mid-hills are the most important agro-ecological zones for producing legume fodder, but some species like red and white clover spread into the high hills because they can withstand lower temperatures. Shrub and tree legumes like Leucaena leucocephala are vital because they offer year-round feed, particularly during the monsoon and post-monsoon seasons when biomass production is at its highest.

Fodder Trees and Shrubs

Woody fodder species supply leaves and branches, especially during dry seasons. They provide 15–29% CP and fill the gaps in green feed (Pandey 1990). In Nepal's many ecological zones, more than 100–136 species are used. *Artocarpus lakoocha*, *Ficus spp*., and *Grewia optiva* are examples of native trees. Multipurpose shrubs such as *Flemingia congesta, Caragana spp., Calliandra calothyrsus*, and *Tephrosia candida* are planted along farm boundaries to preserve soil and provide fodder (NFGRP 2007). Fodder plants and bushes not only provide fuelwood, soil organic matter, and microclimates, but they assist in alleviating forest pressure.

The dry matter (DM), nitrogen (N), and ash levels of several tree and shrub species are displayed in Table 1, suggesting their potential nutritional value as fodder (Fig. 2). Variations in palatability, digestibility, and storability are shown by the wide range of dry matter concentration (30% in *Ficus nemoralis* to 71% in *G. oppositifolia*); species with moderate DM (40– 55%), such as *Dalbergia sissoo* and *Albizia mollis*, provide a good balance between these parameters. The nitrogen content, which indicates crude protein levels and varies from 0.9% (*Saurauia napaulensis*) to 3.4% (*Budleja asiatica*), indicates that leguminous and soft-leaved species like *Albizia mollis, Budleja asiatica*, and *Grewia tiliafolia* are more protein-rich and nutritionally significant. *Erythrina arborescens, Dendrocalamus strictus*, and *Celtis australis* are examples of species that can provide animals with essential minerals. Ash content, a measure of mineral content, varies from 3.1% (*Quercus semicarpifolia*) to 28.8% (*Celtis australis*).

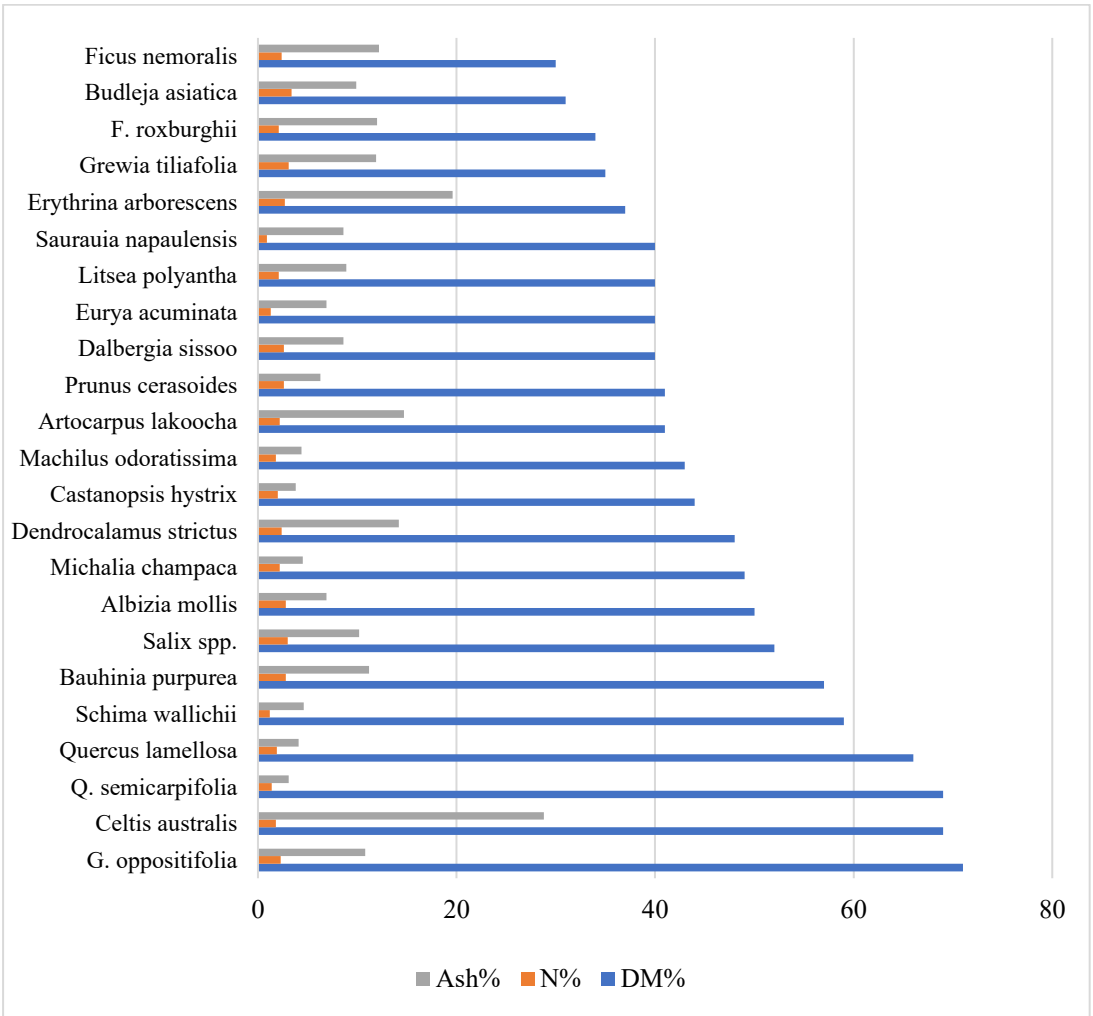

Fig. 2. Chemical composition of fodder trees found in hills of Nepal
(Adopted from Bajracharya et al 1985, Panday 1990, PAC 1982)

Table 3. Growth habit, agroecological zone and seasonal availability of fodder tree species found in Nepal

SN	English name	Nepali name	Scientific name	Growth habit	Primary agro-ecological zone	Seasonal accessibility
1	Pakhauri	Pakhauri	*Ficus glaberrima*	Tree	Mid-hills	Winter–Spring
2	Pink bauhinia, Ebony	Taankee	*Bauhinia purpurea* L.	Tree	Terai, Mid-hills	Winter–Pre-monsoon
3	Fodder fig	Khanaayo	*Ficus semicordata*	Tree	Mid-hills	Winter–Spring
4	Gogan	Gogan	*Saurauia nepaulensis*	Tree	Mid-hills	Winter–Spring
5	Harro	Harro	*Terminalia chebula*	Tree	Terai, Mid-hills	Winter
6	Khasreto	Khasreto	*Ficus hispida*	Tree	Terai, Mid-hills	Winter–Spring
7	Khasru	Khasru	*Quercus semecarpifolia*	Tree	High-hills	Summer
8	Ipil-Ipil	Ipil-Ipil	*Leucaena leucocephala*	Tree	Terai, Mid-hills	Year-round
9	Litsea	Kutmero	*Litsea monopetala*	Tree	Mid-hills	Winter–Spring
10	Monkey jack	Badahar	*Artocarpus lakoocha*	Tree	Terai, Mid-hills	Winter–Spring
11	Tatelo	Tatelo	*Oroxylum indicum*	Tree	Terai, Mid-hills	Dry season
12	Weeping willow	Bains	*Salix babylonica* L.	Tree	Mid-hills, High-hills	Summer
13	Wodier	Dabdabe	*Lannea coromandelica*	Tree	Terai, Siwalik	Winter–Spring
14	Barro	Barro	*Terminalia bellirica*	Tree	Terai, Mid-hills	Winter
15	Black Siris	Kalo Siris	*Albizia lebbeck*	Tree	Terai, Mid-hills	Summer–Monsoon
16	Chuletro	Chuletro	*Brassiopsis hainla*	Tree	Mid-hills	Winter–Spring
17	Coral tree	Faledo	*Erythrina stricta*	Tree	Terai, Mid-hills	Winter–Spring
18	Cutch tree	Khayar	*Acacia catechu*	Tree	Terai, Siwalik	Winter
19	Dudhilo	Dudhilo	*Ficus nemoralis*	Tree	Mid-hills	Winter–Spring
20	Dumri	Dumri	*Ficus racemosa*	Tree	Terai, Mid-hills	Winter–Spring
21	Elephant fig	Kabro	*Ficus lacor*	Tree	Terai, Mid-hills	Winter–Spring
22	Mountain ebony	Koiralo	*Bauhinia variegata* L.	Tree	Terai, Mid-hills	Winter–Spring
23	Mulberry	Kimbu	*Morus alba*	Tree	Mid-hills	Spring–Summer
24	Nevaro	Nevaro	*Ficus rosenbergii*	Tree	Mid-hills	Winter–Spring

(Adapted from Joshi et al 2020, DLS 2022, Dhakal et al 2021, MOALD 2023, Shrestha et al 2018)

Table 3 shows the wide range of fodder tree species in Nepal in terms of growth habit, agro-ecological distribution, and seasonal accessibility. The fact that all of the species on the list are trees emphasizes how important tree-based fodder systems are to the survival of cattle, particularly in mixed agricultural systems. The bulk of fodder trees are found in the Terai and Mid-hills, indicating that these areas have superior climatic and edaphic conditions as well as more tree integration on farms and community forests. Because they can withstand colder temperatures, only a few species such as *Quercus semecarpifolia* and *Salix babylonica* spread into the high slopes. Since most kinds of fodder trees are only accessible from winter to spring, when herbaceous forage is scarce, fodder trees are essential in addressing seasonal feed shortages. Some plants, like *Albizia lebbeck* and *Leucaena leucocephala*, provide year-round or summer-monsoon fodder that contributes to feed stability all year round. Overall, the data demonstrates strong agro-ecological zonation in species distribution and the vital role that fodder trees play in Nepal to increase the supply of fodder, especially during dry and times of shortage.

Seasonal Availability of Forage and Fodder

January to late June is the most important time to feed livestock, particularly in the mid-hills of Nepal. Although the dry matter and CP content of the leaves of fodder trees were quite acceptable, buffalo may not be able to access the nutrients during these periods due to tannin (Provenza 1995) and maybe greater ligno-cellulose bond concentration. It was found that the leaves of

fodder trees have an excellent calcium content (2.20%), presumably due to the binding effect of the tannin and lignocellulose link. Additionally, animals only have limited access to this vitamin (Kamalak 2005). In Nepal's mid-hills, farmers cultivate winter rice because it is unable to get irrigation anyplace during these difficult periods due to the terraces. Because rice crops do not like shade, farmers do not plant fodder trees in rice field bonds. The scientists observed that some bushes, including pigeon peas, stayed green until April during these dry seasons. If such forage or grasses are diluted in the diet with fodder tree leaves, buffalo production may continue during these hard times.

Hay or silage conservation is prompted by the moderate losses that occur during the post-monsoon (October–November) notwithstanding the abundance of natural grasses and agricultural leftovers during the monsoon (June–September). During the critical feed scarcity periods of winter (December–February) and pre-monsoon (March–May), crop wastes, stored fodder, and tree/shrub species such as *Artocarpus lakoocha, Ficus roxburghii*, and *Bauhinia purpurea* are crucial. Although availability to technical inputs, irrigation, and seed supply limit output, cultivated crops including legumes, Napier grass, and oats (*Avena sativa*) can fill in gaps.

Integrated approaches integrating feed conservation, fodder trees, forage production, and indigenous knowledge are essential to ensuring year-round feed availability (Dhakal 2021). *Artocarpus lakoocha* leaf availability peaks in the post-monsoon season and declines as winter and the pre-monsoon season come near. In contrast, Ficus semicordata provides substantial leaves in the winter, when grasses and other green forages are limited, making it an essential source of food during the dry season. *Bauhinia purpurea* leaf availability peaks during the pre-monsoon season, extending the feed supply into the late dry months when alternative fodder supplies are scarce.

Table 4. Looping period of fodder species in Nepal (Modified from Amatya 1990, Paudel and Tiwari 1992)

Ecological Zone	Common/Local Name	Botanical Name	Leaf-Flushing Period
Low hills	Kalo Kabro	*Ficus infectoria*	June – July
	Barro	*Terminalia bellerica*	March – April
	Kavro	*Ficus lacor*	January – February
	Kutsimlo	*Schefflera venulosa*	January – February
	Koiralo	*Bauhinia variegata*	November – March
	Asna	*Terminalia tomentosa*	December – March
	Badahar	*Artocarpus lakoocha*	October – March
	Pakhuri	*Ficus glaberrima*	December – April
	Pipal	*Ficus religiosa*	October – May
	Bakaino	*Melia azedarach*	May – July
	Tanki	*Bauhinia purpurea*	November – March
	Sal	*Shorea robusta*	March – June
	Harro	*Terminalia chebula*	October – November
	Dabdabe	*Garuga pinnata*	October – May
Mid-hills	Maidalo	*Xylosma controversum*	December – March
	Chilaune	*Schima wallichii*	March – June
	Lankuri	*Fraxinus floribunda*	May – July
	Kalo Chuletro	*Brassaiopsis glomerulata*	May – June
	Bhimal	*Grewia optiva*	October – March
	Kutmero	*Litsea monopetala*	December – March
	Ginderi	*Premna integrifolia*	November – February
	Thotne	*Ficus hispida*	January – March
	Phaledo	*Erythrina arborescens*	October – December
	Jhyanu	*Eurya acuminata*	April – June
	Berulo	*Ficus clavata*	Throughout the year
	Kalikath	*Myrsine capitellata*	December – March
	Painyu	*Prunus cerasoides*	February – July
	Bhakimlo	*Rhus javanica*	June – September
	Gogan	*Saurauia nepaulensis*	December – March
	Nimaro	*Ficus auriculata*	November – January

Ecological Zone	Common/Local Name	Botanical Name	Leaf-Flushing Period
	Rai Khanin	*Ficus semicordata*	December – February
	Dudhilo	*Ficus neriifolia*	October – May
	Dar	*Boehmeria regulosa*	January – March
	Gayo	*Bridelia retusa*	December – February
	Kaulo	*Machilus odoratissima*	January – March
	Pate	*Eurya cerasifolia*	April – June
	Rato Siris	*Albizia mollis*	April – June
	Lodh	*Symplocos crataegoides*	December – March
	Chiuri	*Bassia butyracea*	November – March
	Seto Chuletro	*Brassaiopsis hainla*	May – June
	Bhimsenpati	*Buddleja asiatica*	May – June
	Dhalnekatus	*Castanopsis indica*	April – June
	Khari	*Celtis australis*	April – October
	Lapsi	*Choerospondias axillaris*	September – November
High hills	Khasru	*Quercus semicarpifolia*	November – April
	Demmar	*Cornus capitata*	January – March
	Dur Kaphal	*Prunus paddus*	January – March
	Sano Phalant	*Quercus glauca*	Throughout the year
	Thulo Phalant	*Quercus lamellosa*	March – October
	Banjh	*Quercus lanata*	October – June
	Sano Banjh	*Quercus leucotrichophora*	November – April
	Bains	*Salix* spp.	Throughout the year
	Pangro	*Aesculus indica*	May – October
	Patle Katus	*Castanopsis hystrix*	January – June
	Musure Katus	*Castanopsis tribuloides*	December – March
	Kimbu	*Morus alba*	January – October
	Bhotepipal	*Populus* spp.	June – September

By summarizing the lopping times of important fodder species throughout Nepal's three main agro-ecological zones low hills, mid-hills, and high hills Table 4 illustrates the seasonal availability of tree and shrub fodder for cattle. The lopping times of fodder species in the low hills vary; some, such as *Terminalia chebula* (Harro) and *F. infectoria* (Kalo Kabro), have shorter windows that correspond to seasonal growth patterns, while others, such as *B. variegata* (Koiralo) and *Ficus lacor* (Kavro), are available for most of the year. A greater variety can be found in the mid-hills, where some species, like *Erythrina arborescens* (Phaledo) and *Fraxinus floribunda* (Lankuri), are only available in specific months, while others, like *F. clavata* (Berulo) and *Albizia mollis* (Rato Siris), are available year-round or for prolonged periods of time. While some species, like *Prunus paddus* (Dur Kaphal) and *Cornus capitata* (Demmar), are only available in the winter and early spring, species with longer or continuous availability, like Quercus glauca (Sano Phalant) and Salix spp. (Bains), are usually found in high hills.

Fodder Tree Contribution in Agroforestry Systems

From October to May, fodder trees generate high-protein biomass. *Artocarpus lakoocha, Ficus semicordata*, and *Leucaena leucocephala* are a few plants that significantly enhance ruminant diets and reduce the burden on forests. They supply fuelwood, prevent erosion, increase soil fertility, and support biodiversity. Indigenous knowledge directs species selection, propagation, and management (Tamang et al 2024). Obstacles that necessitate market expansion, policy assistance, and credit availability include limited technical experience, insufficient planting materials, and extension support (NFGRP 2007).

Feed resources are most plentiful during the monsoon season (June–September), when natural grasses grow rapidly and provide most of the animal feed. After the monsoon, there is a progressive decline in feed availability, which peaks in December and February. At this time, there is a significant feed gap, primarily due of the sharp drop in wild grasses and farmed forages caused by the cold and unfavorable growing circumstances. Cultivated forages, such as oats, Napier, and Stylosanthes, remain scarce during the winter despite helping to alleviate feed shortages. Tree fodder has a stabilizing impact because it is typically available all year round and becomes particularly important in the winter and prior to the monsoon. The post-monsoon and winter months are when crop wastes are most accessible after harvest. They are an essential backup feed supply during times of scarcity despite their low quality.

Genetic Diversity and Utilization

Nepalese forage and fodder plants, including grasses, legumes, shrubs, and trees, are suitable for a range of agro-ecological zones and are crucial for animal nutrition (Dhakal et al 2021). Genetic variety not only boosts food content and productivity but also promotes tolerance to climate, pests, and diseases. More than 500 species, both indigenous and foreign, are available. Molecular and field research reveals polymorphism and variation in biomass and physical traits, offering opportunities for conservation and breeding.

Indigenous knowledge influences the utilization of forage; species such as *Brassaiopsis hainla*, *Ficus semicordata*, and *Artocarpus lakoocha* are valued for their palatability and performance. The challenges include limited seed supply, seasonal shortages, poorly defined resources, and climate consequences (Dhakal et al 2021). There is conservation using both in situ and ex situ techniques, participatory varietal selection, and the integration of forage species into cropping systems. Enhancing genetic characterization, seed systems, and farmer knowledge might enhance livestock production and sustainable consumption in addition to breeding programs (Dhakal et al 2021, Subedee et al 2022).

Table 5. Diversity and utilization of the Major Species for Fodder and Forage

SN	English Name	Nepali Name	Scientific Name	Genetic Diversity	Utilization Status	Breeding and Conservation Initiatives
1	Chuletro	Chuletro	*Brassaiopsis hainla*	Moderate	traditionally utilized fodder tree in Nepal's mid- and high-hill regions	maintained largely through farmer-managed systems and in situ conservation in mountainous landscapes
2	Oat	Jai	*Avena sativa*	Moderate	Cultivated crop	breeding efforts mainly focused on yield stability and drought tolerance under rainfed conditions
3	Himalayan nettle	(Allo)	*Girardinia diversifolia*	High	locally utilized for fiber and fodder	field-based evaluation and molecular characterization to support its conservation and improvement
4	Monkey fruit	(Badahar)	*Artocarpus lakoocha*	High	underutilized multipurpose tree species in Nepal	conserved and disseminated mainly through indigenous knowledge and traditional agroforestry practices
5	Berseem clover	Berseem	*Trifolium alexandrinum*	Moderate	widely cultivated in the Terai as a winter fodder legume	ongoing efforts to strengthen both formal and informal seed systems
6	Napier grass	Napier Ghaans	*Pennisetum purpureum*	High	cultivated across agro-ecological zones	continuous development of improved cultivars and participatory varietal selection to enhance biomass yield and adaptability

(Adapted from (DFRS 2015, ILRI 2011, Joshi et al 2018, MOALD 2020).

The diversity, utilization, and conservation or breeding efforts of Nepal's major fodder and forage species are displayed in Table 5. It illustrates the importance of plants like *Pennisetum purpureum* (napier grass) and *Girardinia diversifolia* (Himalayan nettle) in cow nutrition, as well as their widespread or local use. Despite their great diversity and underutilization, some species, including *Artocarpus lakoocha* (monkey fruit), show potential for broader acceptance. *Trifolium alexandrinum* (Berseem clover), *Avena sativa* (Oat), and *Brassaiopsis hainla* (Chuletro) are a few examples of relatively diversified plants that are either farmed or used traditionally, with varying degrees of formal breeding or conservation efforts. Overall, the graph indicates opportunity for enhancing genetic utilization and sustainable livestock feeding methods in Nepal, even if some significant fodder and forage species are actively used and improved through conservation or breeding activities.

Agronomical practices for cultivation of forage and fodder species

Nepal's livestock production systems depend heavily on forage and fodder crops, which boost animal productivity and supply year-round feed. Site-specific management, such as planting time, seed rate, sowing techniques, and ground preparation, has a significant impact on the agronomic performance of these crops. According to research, plowing and scouring the soil prior to planting greatly improves germination and early establishment of crops including feed sorghum (*Sorghum bicolor*), oats (*Avena sativa*), and maize (*Zea mays*) (Rai 2024).

It is crucial to choose forage species and varieties that are suitable for the Terai, mid-hills, and high-hill ecologies. For instance, napier grass (*Pennisetum purpureum*) does well in the Terai, while forage pea (*Pisum sativum* L.) and cowpea (*Vigna*

unguiculata) exhibit high biomass and crude protein yield in the mid-hills (Ghimire et al 2021, Dhakal 2021).

While organic additives like farmyard manure enhance soil health and forage digestibility, fertilizer management especially the application of nitrogen and phosphorus is essential for raising dry matter yield and protein content (Rai 2024). While legumes often need less frequent irrigation, water management through irrigation is crucial during dry spells, especially for maize and sorghum (Dangi 2020). In order to improve soil fertility and total biomass, intercropping cereals with legumes has become popular. For example, systems that combine oats and vetch and maize and cowpea have been demonstrated to boost forage output by 15–25% when compared to monocropping (Rai 2024, Dhakal 2021).

In order to minimize losses, integrated techniques such as mechanical weeding and biocontrol agents are advised. Weed, pest, and disease management are still major obstacles (Sharma 2018). Adoption of better foraging techniques is greatly influenced by socioeconomic variables.

The successful application of agronomic methods depends on a number of factors, including extension support, livestock holding size, loan availability, farmer awareness, and access to high-quality seeds (Dhakal 2021). With the goal of reducing feed deficits and promoting sustainable livestock intensification, national programs like the Forage Mission and Livestock Feed Development Programs have encouraged the production of better fodder varieties throughout Nepal (Sharma 2018, Rai 2024). In order to increase adoption and boost the productivity of forage-based livestock systems in Nepal, participatory research, extension-based training, and policy interventions are required. These challenges include limited seed systems, low mechanization, and climatic stresses (Ghimire et al 2021, Dangi 2020).

Challenges and Opportunities

Outside of the monsoon, Nepal's ongoing feed shortages force people to rely on forest fodder, agricultural waste, and scarce farmed forages, which lowers productivity and nutrition (Sharma 2015, Sharma 2018, FAO 2018). Particularly impacted are the Terai and mid-hills, where forest and pasture resources are insufficient for a year-round supply. The amount of fodder produced is decreased by topographical, climatic, and soil limitations as well as a lack of superior seeds. Natural pasture deterioration brought on by overgrazing and conflicting land use further restricts the supply of feed (FAO 2018). Indigenous knowledge aids in species selection and seasonal feeding methods, even though it is not always included into government initiatives (Tamang et al 2024). Climate change necessitates adaptive foraging strategies (Dhakal 2021). Opportunities include using degraded lands and community forests, promoting high-yielding forage cultivars, integrating forages into cropping systems, expanding extension services, strengthening seed systems, and putting climate-smart interventions like integrated agroforestry and drought-tolerant species into practice (Sharma 2015, FAO 2004, Tamang et al 2024).

Livestock production is limited by a number of factors, including seasonal feed shortages, a lack of improved forage seeds, the degradation of natural pastures, difficult topography and climate conditions, and insufficient extension support for farmers. These factors lead to decreased cattle productivity and an inadequate and unpredictable feed supply. Opportunities include the adoption of high-yielding forage cultivars, the integration of agroforestry and pastureland systems, the strengthening of forage seed systems, the promotion of climate-smart forage species, and community-based management and extension techniques.

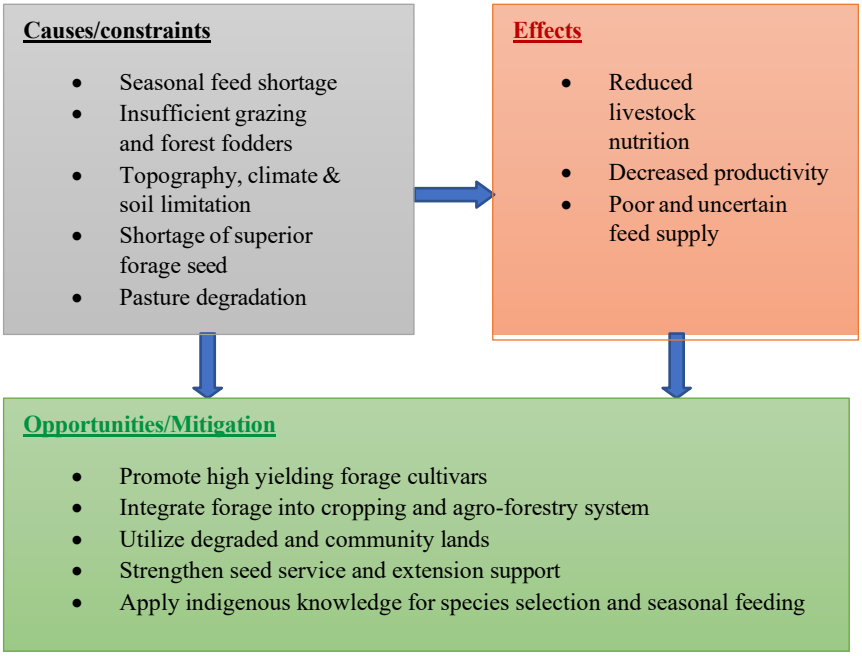

Fig. 3. Constraints, effect and opportunity of forage and fodder species in Nepal

Fig. 3 illustrates the primary constraints, implications, and prospects associated with Nepal's fodder and forage species. It highlights problems including limited supplies, unpredictable seasons, and low adoption of better species that reduce cattle output. The benefits of these species for agricultural income, animal nutrition, and ecological sustainability are also highlighted in the picture. The introduction of high-yielding species, improved management strategies, and integration into cropping systems are examples of opportunities to boost the production of fodder and forage, providing choices to improve sustainable agriculture in Nepal and support livestock-based incomes.

CONCLUSION

Nepal's livestock productivity is severely hampered by seasonal feed shortages, the lack of planted fodder, and the devastation of natural pastures. These problems affect animal growth, reproduction, and overall productivity, particularly in the winter and before to the monsoon. Despite these disadvantages, Nepal offers significant opportunities to develop livestock systems that are climate-resilient and sustainable due to the country's high genetic variety of fodder and forage species. The future research should concentrate on the creation of high-yielding and nutrient-dense variety, the genetic characterization of both native and improved species, and the spatial mapping of feed resources to optimize their utilization. By using genetic variation through targeted breeding, conservation, and better management practices, Nepal can increase livestock productivity, bolster year-round feed security, and support the livelihoods of rural inhabitants.

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AUTHORS' CONTRIBUTION

S Rai conceptualized, reviewed the literature and prepared the manuscript.

CONFLICT OF INTEREST

The authors have no any conflict of interest to disclose.

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