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Temperate Grasslands: Future Outlook and Food Security in a Changing Climate

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Grasslands, covering about 26% of Earth's land and 80% of agricultural land, are vital for food production and ecosystem services. They include diverse ecosystems like rangelands, shrublands, and pasturelands, playing crucial roles in supporting biodiversity, soil carbon storage, and livestock production. In the Indian Himalayas, grasslands span 35% of the region, including various types like warm temperate, sub-alpine, and alpine meadows, contributing significantly to ecology and livestock productivity. However, these ecosystems face severe challenges due to climate change, poor management, and overgrazing. The degradation of grasslands in the Himalayas, driven by relentless resource exploitation, has led to erosion and reduced biomass, impacting livestock production. To combat these issues, strategies such as reseeding with elite native grasses, legume introduction, improved grazing management, and multi-stakeholder collaboration are essential. Globally, grasslands are also threatened by climate change, which affects species composition, productivity, and forage quality. The United Nations General Assembly's declaration of the International Year of Rangelands and Pastoralists in 2026 aims to highlight these challenges and promote sustainable practices. Effective management and anticipatory measures are crucial to mitigate climate change impacts and ensure the resilience of grassland ecosystems, supporting both human and animal populations.

Introduction

Grasslands are highly dynamic ecosystems providing goods and services to support flora, fauna, and human populations worldwide. Spanned approximately 3.5 billion hectares, grasslands encompass rangelands, shrublands, pasturelands, and croplands planted with pasture and fodder crops. This area constituted 26 percent of the earth's land surface and accounted for 70 percent of the global agricultural area, containing about 20 percent of the world's soil carbon stocks. The Himalayas are known as one of the most diverse ecosystems globally, with grassland vegetation covering approximately 35% of the Indian Himalayan region. This includes warm temperate grasslands, sub-alpine and cool temperate grassy slopes, alpine meadows across the greater Himalaya, and steppe formations in cold, arid alpine regions or dry scrub areas. These grasslands are distinct in their origin, structure, and composition, forming separate categories within the Himalayan landscape. Rangelands, which encompass various vegetation types, account for about 55% of the total area in the Himalayan region. In Jammu and Kashmir (J&K), productive grasslands covers 4.3% of the geographical area, while other grazing lands, including scrub and unpalatable swards, account for 9.8% of the total area. Globally, grasslands encounter various challenges due to climate change, such as elevated atmospheric carbon dioxide levels, rising temperatures, alterations

in precipitation patterns, and increased ground-level ozone concentrations. These factors threaten productivity, species composition and quality, with potential impacts not only on livestock production but also on other aspects of the multifunctional role of grasslands. Due to poor management and constant grazing, all types of grasslands have been degraded and are found to be less productive. The Himalayas have suffered from relentless exploitation of natural resources, including reckless tree cutting, uncontrolled grazing, and the absence of rehabilitation programs. This has led to severe erosion of hill slopes and critically low biomass availability, significantly affecting livestock production. To enhance productivity, strategies such as fertilizer application, improved grazing management, increased utilization of crop by-products, legumes, and supplements, as well as adjustments in stocking rates and herbage allowance, are essential measures. The United Nations General Assembly (UNGA) has declared the year 2026 as the International Year of Rangelands and Pastoralists (IYRP) that aims to celebrate and raise awareness about the importance of rangelands and pastoralists worldwide. This initiative seeks to highlight the challenges faced by pastoralists, including land degradation, climate change impacts, and socio-economic marginalization. It also aims to promote sustainable practices and policies that ensure the resilience and well-being of rangelands and pastoralists.

Flora and biomass production

In the flora of western Himalaya, grass family occupies the top position in terms of species number. The above-ground biomass in these grasslands varies from 1,000 kg/ha to 10,000 kg/ha for warm temperate grassland and 400–5,000 kg/ha for high altitude grasslands. In parts of Garhwal and Kumaon Himalaya, the standing biomass of grasses was found to increase with increasing altitude up to about 3,750 m. The dry matter yields (in kg/ha) of certain indigenous fodder grasses (within pure stands) are reported to be up to 7,440 for *Andropogon pumilus*, 11,040 for *Apluda mutica*, 6,986 for *Arundinella nepalensis*, 6,951 for *Bothriochloa intermedia*, 4,975 for *Chrysopogon fulvus*, 6,941 for *Chrysopogon gryllus*, 6,925 for *Heteropogon contortus*, 9,918 for *Pennisetum orientale* and 4,836 for *Themeda anathera*. In terms of nutrient value, i.e. crude protein content, *Apluda mutica*, *Bothriochloa intermedia* and *Chrysopogon fulvus* are considered to be the best for grazing. Maximum green (48.38 t/ha) and dry fodder yield (12.58 t/ha) was obtained from harding grass (*Phalaris aquatica*) followed by tall fescue (*Festuca arundinaceae*) with values 37.38 and 9.72 t/ha respectively for green and dry fodder yields. Minimum green (21.28 t/ha) and dry fodder yield (5.53 t/ha) was obtained in *Chrysopogon gryllus*. Among legumes, maximum green (41.50 t/ha) and dry fodder yield (10.79 t/ha) was obtained in Sainfoin (*Onobrychis viciifolia*) followed by red clover (*Trifolium pratense*) and alfalfa. Minimum green (17.40 t/ha) and dry fodder yield (4.52 t/ha) was obtained from crown vetch (*Coronilla varia*). However, legumes had comparatively higher values for crude protein yield with higher values for sainfoin (1931.4 kg/ha), alfalfa (1670.1 kg/ha) and red clover (1631.8 kg/ha). Among grasses highest crude protein yield (1500.6 kg/ha) was found in rye grass (*Lolium multiflorum*) followed by (*Bromus uniolodies*) Praire grass (1145.7 kg/ha), harding grass (1065.2 kg/ha), (*Phleum pratense*) timothy (1038.9 kg/ha) and (*Dactylis glomerata*) orchard grass (986.8 kg/ha).

While the growing season in the temperate region generally begins in April, the sub-alpine and alpine grasslands start sprouting in June to July. Thus, the biomass production in these grasslands is lower than in tropical grasslands due to the shorter growing season. The reckless and indiscriminate cutting and grazing are the important factors leading to the deterioration of these grazing lands. Despite the fact that domestic animals are an integral part of agro-pastoral ecosystems and that grazing-based animal husbandry is the mainstay of the economy in many parts of the Himalaya, no studies and policy guidelines are available for optimal use of grazing resources. The deterioration of pastures, grasslands and other grazing

lands may be ascribed to the large bovine population, over stocking and proliferation of noxious and poisonous weeds, free grazing practices, lack of management, and natural constraints like extremes of temperature, steepness of slopes, variable precipitation, shrinkage of village pastures previously ear-marked for grazing of livestock called “Gass charaie” due to population pressure through constructions viz., illegal encroachments, shrinkage of cultivable land under fodders due to pressure on agricultural land for food and cash crops, failure to produce fodder crop seeds by private/public agencies and lack of large-scale dissemination of improved fodder production technology.

A serene pastoral scene featuring a diverse herd of sheep and goats grazing on a lush green pastureland amidst a backdrop of dense pine forests and a rustic wooden and mud hut.

Grasslands and the food security

Since 1950, the global population has increased dramatically, soaring from under three billion to nearly seven billion today. Projections indicate it will surge to 9.3 billion by 2050 and could reach ten billion by the century's end. The bulk of this growth is anticipated in Asia, Latin America, and Africa, with populations in more-developed regions expected to remain relatively stable through 2050.The greatest demographic expansions are anticipated in the least-developed countries and other less-developed regions, excluding the least-developed countries. The world's food production system faces substantial challenges due to these factors. More than 800 million people worldwide have very low incomes, with an additional 200 million residing in marginal arid and semi-arid areas, relying heavily on grasslands for their livelihoods. Increasing incomes and population growth are major drivers of heightened food demand. As incomes rise, particularly in countries experiencing gradual economic improvement, consumers tend to allocate a larger share of their additional earnings toward their dietary needs. The regions expected to experience particularly robust food demand include Eastern Europe, Asia, and Latin America, with less vigorous demand anticipated in sub-Saharan Africa and stagnant demand in developed countries. Globally, extensive pastoral systems dominate most dry zone regions, where agricultural production tends to be marginal and often confined to small portions of the landscape. Examples of such zones include Sub-Saharan Africa, northern Australia, and parts of South America. Pastoral and semi-natural or marginal areas collectively account for 47% and 36%, respectively, of total grasslands globally. These systems are often dominated by herbaceous plants and/or shrubland, and are

often populated by communal and nomadic peoples with livestock comprising cattle, sheep, goats and camels that are primarily dependent on pasture, which provides almost all the feed. Globally, these systems provide all 7% of beef, 12% of sheep meat and 5% of milk production.

The food products from grassland are milk and meat from ruminant animals. Ruminant animals can be fed on high-grain diets, but usually their diet involves some grazed or conserved grass or other fodder crop. Therefore, while grass is seldom the sole food in ruminant production systems, particularly in developed countries, it usually constitutes a major component of the diet. Milk makes a substantial contribution to global food supply, providing two-thirds as much food energy as total meat production and twice as much energy as ruminant meat alone. This underscores its significant role in the global food energy landscape.

Challenges of climate change

Climate change and variability are concerns of human being. Globally, climate change is the most serious environmental threat that adversely affects agricultural productivity. Climate change impacts to grasslands and prairie bioregions include increased seasonal, annual, minimum, and maximum temperature and patterns. Increasing temperatures, reduced rainfall, and drought are already being observed in some regions, and the arid Southwest in particular is projected to become even drier in this century. In wetter region, forests are expected to encroach upon existing savannas. Conversely, in areas becoming progressively drier, deserts are predicted to both expand in size and migrate to higher elevations, thereby triggering the process of desertification within arid grassland ecosystems. Even slight changes in temperature and precipitation can significantly impact the composition, distribution, and abundance of species in arid lands, as well as the products and services they offer. The impacts of climate change may be discussed briefly as follows:

(i) **Elevated temperatures:** Warmer temperatures are expected to boost the growth of C3-dominated grasslands in response to elevated CO2 levels, thereby increasing productivity, especially in areas where water availability is not a limiting factor. In high- and mid-latitude rangelands, which currently face constraints on growth due to cold temperatures, warmer conditions alone are likely to enhance production. This increase in growing degree days could potentially allow for additional harvest opportunities. However, drought conditions reduce the quantity and quality of available forage for grazing livestock, posing a threat to pasture and feed supplies.

(ii) **Elevated carbon dioxide:** Carbon dioxide (CO_2) enrichment and global warming are believed to increase net primary productivity (NPP) of most of the temperate pastures and rangelands. Due to slow canopy-level evapo-transpiration as a result of reduced stomatal conductance, leading to reduced rate and extent of soil water. The available evidence suggests that forage legumes in general show higher responses than grasses to elevated CO_2 .A doubling in the concentration of CO_2 increased tissue C: N ratio by 15% on average mainly reflecting the increase in carbohydrate content.

(iii) **Changes to precipitation patterns and increased environmental variability:** The productivity of most rangelands is primarily limited by water availability, which changes proportionally with variations in total annual rainfall. This factor profoundly affects these ecosystems, particularly in arid and semi-arid regions, although shifts in seasonal precipitation patterns and storm intensity may have even greater impacts. Elevated CO2 levels could potentially enhance water use efficiency (WUE), partially offsetting the effects of reduced summer precipitation and increased potential evapotranspiration. The distribution of species within rangelands is largely determined by their water balance, highlighting the ecological importance of

increased environmental variability. Projections indicate that Central Europe could experience a doubling of inter-annual temperature variability by 2071-2100, along with increased winter rainfall and decreased summer precipitation. These environmental shifts might result in more frequent gap formation and the introduction of new species, presenting challenges for managing desired species compositions under future climatic conditions, particularly during extreme events like summer droughts.

(iv) **Changes in species distribution:** In warm humid climates, C4 species are typically favored over C3 species, whereas the opposite holds true in cooler climates. The increasing minimum daily temperatures associated with global warming are expected to further benefit C4 plants, as they promote higher levels of photorespiration and reduce the quantum yield in C3 plants. However, elevated levels of CO2 may partially counterbalance these effects by favoring C3 grasses and broadleaved species. Nonetheless, predictive analyses indicate that the relative abundance of C4 grasses in temperate grasslands is projected to increase across most regions of North and South America.

(v) **Changes in forage quality and herbivory:** The quality of forage is influenced by several factors including digestibility, protein and energy content, palatability, and levels of mineral and anti-nutritional components. These factors are sensitive to the growing conditions of grasslands, and the impacts of elevated CO_2, warmer temperatures, and altered rainfall patterns may have conflicting effects on these quality components. It is anticipated that forage quality may decrease under elevated CO_2 levels due to higher carbon-to-nitrogen ratios and potentially increased concentrations of unpalatable or toxic compounds in plants. Additionally, plants grown under elevated CO_2 typically exhibit lower mineral concentrations (excluding phosphorus) compared to those grown under ambient CO_2 conditions. While higher forage intake might compensate for declining quality, herbivores such as ruminants and functional caecum animals are likely to experience reduced consumption and productivity because intake is largely regulated by the rate of ingest passage, which decreases with declining diet quality.

Grasslands and Pastoralism in the Himalaya

The temperate grasslands of India are primarily located in the Himalayan region, encompassing states like Himachal Pradesh, Uttarakhand, and parts of Jammu and Kashmir. These grasslands, found at elevations ranging from 1,500 to 3,500 meters, include sub-alpine meadows, grassy slopes, and alpine pastures. They are characterized by a rich diversity of grasses, herbs, and shrubs, providing crucial habitats for various wildlife species and acting as key grazing grounds for livestock. Pastoralism in these temperate grasslands has been a traditional livelihood for many communities, including the Gujjars, Bakarwals, Chopans, Gaddies, Changpas, Van Gujjars, Bots, etc. These pastoralists practice transhumance, migrating with their herds seasonally to access the best grazing areas. During the summer, they move to higher altitudes, while in winter, they descend to lower elevations. This practice ensures sustainable use of the grasslands, preventing overgrazing and allowing vegetation to regenerate. However, the temperate grasslands of India face challenges from climate change, land degradation, and increasing pressures from tourism and development. These factors threaten the delicate balance of these ecosystems and the pastoralist way of life. To address these challenges, sustainable management practices are essential, such as rotational grazing, the protection of critical habitats, and policies supporting the rights and livelihoods of pastoral communities. Preserving these grasslands is vital for maintaining biodiversity, supporting traditional pastoralism, and ensuring ecological stability in the region.

***Dactylis glomerata* L. (**10-12 t DM /ha; Crude Protein : 28.3% to 12.5 % (late bloom stages)

***Bromus unioloides* (**7.0 t DM/ha: Crude Protein:14%)

Sainfoin (Fodder yield: 14-16 t/ ha; Crude Protein: 20 %)

Red clover (Green fodder yield 40-60 t/ha; Crude Protein: 22%)

Tall fescue. (Fodder yield 10-12 t DM/ha**;** Crude Protein: 13 %)

***Phalaris* aquatica** (Green fodder yield: 65-70 t/ha; Crude Protein: 14 %)

Important temperate fodder and grasses and legumes

Conclusions

Grasslands cover about 26% of Earth's land area and 80% of agriculturally productive land, providing essential ecosystem services, supporting biodiversity, and playing a critical role in food production. In the Indian Himalayan region, diverse grasslands, including warm temperate, sub-alpine, and alpine meadows, significantly contribute to the region's ecology and livestock production. However, global grasslands face challenges from climate change, poor management, apathy of various stakeholders and overgrazing. In the Himalayas, over-exploitation has led to severe erosion and reduced biomass, impacting livestock productivity. To enhance productivity, better management practices such as reseeding, controlled grazing,

and the use of legumes and supplements are essential. These factors threaten productivity, species composition and quality, with potential impacts not only on livestock production but also on other aspects of the multifunctional role of grasslands. The United Nations General Assembly's declaration of the International Year of Rangelands and Pastoralists-2026 aims to promote sustainable practices and raise awareness about the importance of these ecosystems. The appropriate anticipatory measures need to be taken to prevent and reduce the wrath of climate change on grassland production and animal and human survival. ICAR-IGFRI and its Regional Stations in Srinagar and Palampur that have been working on different forage grasses and legumes (orchard grass, tall fescue, Harding grass, *Bromus*, ryegrass, timothy, sainfoin, red and white clovers) need to be popularized, encouraging farmers/pastorals to cultivate these crops in lands unsuitable for rice cultivation, free spaces in fruit orchards, field bunds, forest plantations, grasslands and other unutilized areas. These grasses and legumes will provide balanced feed for extended periods due to their perennial nature and drought hardiness.

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