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Research Article

Grasslands: Productivity and Biomass

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Abstract

Grassland is one of the most widespread vegetation types worldwide and plays a prominent role in ecological security and human development. Three important factors have been responsible for the evolution and maintenance of the grassland ecosystem: drought, fire and grazing. The naturally occurring grasslands, primarily determined by climate, occur in areas where growth of forests is prevented by non-availability of sufficient soil water. In addition to the climatically determined natural grasslands, successional grasslands are maintained by removal of original forest vegetation as a consequence of grazing, mowing or burning. For their importance in ecological productivity, studies of their biomass and ecological productivity is very important. A number of different methods and models have been used to estimate their biomass production and productivity. Every method has its own merits and demerits. Even though alternatives to the conventional harvesting methods have been devised, the conventional harvesting methods for ecological productivity are still in vogue. The research attributes the role of precipitation and temperature in regulating productivity in grasslands. Probably because of more favourable environmental conditions throughout the year, tropical grasslands are more productive on an annual basis than their other counterparts. Similarly different species in a grassland may respond differently to the amount, occasions and type of precipitation. The plant biomass and productivity in grasslands is not affected only by present year precipitation but also by previous year precipitation amount and pattern. The productivity of C_3-species and C_4 species also respond differently to mean annual temperature and mean annual precipitation. Different types of biotic stresses also affect plant biomass and primary productivity the most important biotic stress among them is grazing. Although heavy grazing and no grazing in general decreases productivity, moderate grazing has positive effects on productivity. Aboveground and below ground biomass is also affected by both abiotic and biotic factors. The outcome of different ecological factors result in the amount and ratio of aboveground and belowground (living and dead biomass)

Keywords: *Grassland, biomass, aboveground, belowground, productivity, grazing.*

Introduction

Grassland is one of the most widespread vegetation type worldwide [1] and plays a prominent role in ecological security and human development [2, 3]. Grasslands constitute an ecosystem characterized by grass dominance with little tree cover [4, 5]. UNESCO (https://www.unesco.org/en.) defines grassland as "land covered with herbaceous plants with less than 10 per cent tree and shrub cover". Gibson [6] defined grassland 'as any plant community, including harvested forages, in which grasses and/or legumes make up the dominant vegetation'. White *et al.* [7] also defined grassland as "terrestrial ecosystems dominated by herbaceous vegetation". They are among the most widespread biomes worldwide and in general have non-woody plant species. This vegetation type harbours a high diversity of plant species that mostly occurs at fine spatial scales because grasslands tend to be structurally simpler at coarser scales [8]. There are varied estimates about the area occupied by

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grasslands. For example Whittaker and Likens [9] reported an area of 24.0 million Km^2 (16.1%) under grasslands. While other studies put the value as 20.7% [10], 23.7% [11], 26% [12], 27% [13] to 40% [14, 15]. Before, the impact of humans, the grasslands covered at least 40% of the earth's land surface [16]. Grasslands occur nearly on all continents except Antarctica [17]. They are most commonly found in arid and semi-arid zones (47% of the world's grasslands), followed by humid (23%), and cold (20%) regions [7]. Three important factors have been responsible for the evolution and maintenance of the grassland ecosystem: drought, fire and grazing [18]. The naturally occurring grasslands primarily determined by climate, occur in areas where growth of forests is prevented by non-availability of sufficient soil water [19]. In addition to the climatically determined natural grasslands, successional grasslands are maintained by removal of original forest vegetation as a consequence of grazing, mowing or burning [20]. Grasslands with all forms are home to a myriad of plant and animal species. They provide forage for more than 1800 million livestock units and wildlife populations [21, 17]. For the livestock it makes upto 90% of their feed [22]. Moreover, they constitute approximately 70% of the world's agricultural areas, which translates to around 34.3 million km^2 [7, 23]. These vast areas of lands also directly or indirectly support over 800 million of human populations with abundant natural resources for the production of food, fuel, fibre, medicine, recreational and educational benefits [24, 25, 21, 26, 17, 27, 28, 29, 30]. Their importance is further substantiated by the fact that a significant contribution of global primary productivity is contributed by grasslands [31], estimated to be about 1.89×10^{10} tons yr^{-1} [9]. Grasslands generate approximately 10% of terrestrial plant biomass and hold roughly 30% of the planet's soil organic carbon reservoirs [32]. They also play a substantial role in regulating the material circulation, energy flow and biodiversity in the biosphere [14, 15, 28, 29]. As grasslands provide valuable ecosystem multi-serviceability [4, 33, 34], therefore understanding their trends in productivity [35] warrants insights into their structure and functioning. It is also important to study their biomass production and productivity dynamics as it has become more vulnerable to human interference, climate change, and their interactions [7, 36, .37, 28, 38].

Productivity is the amount of organic substance acquired by an individual, population or a system per unit time. The term productivity in ecological sense was probably first used by Richard Bradely (1688-1732) [39]. Productivity falls into two major categories, one is primary productivity, i.e. by photosynthetic organisms. The other is secondary productivity, i.e. by organisms not capable of photosynthesis. Each of these is subdivided into gross and net productivity. At ecosystem level, green plants are energy transducers. They capture and fix solar energy and this energy is captured in the form of accumulated biomass. This is gross primary productivity (GPP). GPP represents the material and energy that initially enters a terrestrial ecosystem and directly reflects the productivity of the terrestrial ecosystem under natural conditions [40]. But part of the matter accumulated through photosynthesis is respired, used up by the plants' metabolism. Gross productivity minus respiratory loss is called net primary productivity that we can realistically measure; gross primary productivity is usually simply a logical construct. Roxburgh *et al.* [41] defined net primary productivity (NPP) as the amount of organic matter produced through photosynthesis by ecosystems per unit time and unit area. It can also be described as the sum of gross carbon fixation by autotrophic carbon-fixing tissues per unit area and time i.e., gross photosynthesis minus photorespiration [42, 43]. NPP is sensitive to climate change, which consequently, can reflect the health status of vegetation and the ecological quality to a certain extent [44, 45].

A number of different methods have been used to estimate the level of net primary productivity [46]. The simplest method is one in which the whole stand of plants together with roots (plant biomass) is collected at successive sampling dates. Thus measurement of biomass is an indirect measure of the primary productivity of an ecosystem. Since biomass units and energy units are inter-convertable, and biomass can be expressed as the amount of carbon, primary productivity therefore, can be measured as carbon or energy taken up by the plant or as the amount of increase in plant biomass, carbon or energy content. However, this method though in vogue has a lot of limitations [47, 48]. Many researchers have used this method or its variants to estimate grassland productivity. Friedl *et al.* [49] estimated grassland biomass and productivity using ground and satellite data. Haugland [50] developed a simple model to relate dry biomass to the proportion of dicots present in grasslands. Besides biomass harvest methods, different methods, models and techniques have been followed in recent times, to estimate productivity of grasslands [46]. Even very early Stout [51] used simulation of production and utilization of the rangeland (SPUR) model to evaluate productivity in an annual grassland in northeast USA. Similarly Chladil and Nunez [52] also used remote sensing and empirical models to assess biomass of grasslands in Southeast Tasmania, Australia. Teague and Foy [53] used this model for estimating plant biomass in a grassland in Texas USA. Eddy covariance methods can be used to obtain gross primary productivity (GPP) by measuring the net ecosystem exchange (NEE) between the biosphere and the atmosphere [54]. The eddy covariance method is a statistical technique used in meteorology and other fields to determine exchange rates of trace gases over natural ecosystems and agricultural fields, as well as quantify gas emissions rates from other land and water areas. This method has become the most important method for measuring CO_2 exchanges between vegetation and the atmosphere and is also an internationally recognized standard method for measuring carbon fluxes [55]. Statistical models, also known as climate productivity models, are used to estimate vegetation productivity by establishing mathematical models through several common statistical methods according to the relationships between plant biomass changes and climate factors. For example, the Miami model [56], Thornthwaite model [57] and Chikugo model [58] have been widely used in regional GPP estimations. Based on the Miami model, the Thornthwaite model provides more accurate values. Furthermore, considering that the absorption of photosynthetically effective radiation by vegetation canopies is one of the leading factors affecting photosynthesis, the Chikugo model adds the radiation dryness index and net radiation to calculate vegetation productivity, providing a more accurate description of productivity [46]. However, when applied in arid and semi-arid grassland areas, the values estimated by these models are high (Wen *et al*., 2014) [59]. The correlation between these two factors gradually decreases, failing to reflect the response of the carbon sequestration process to climate change [46]. Ecological process models, also known as mechanism models, are based on physiological and ecological mechanisms associated with vegetation growth and development in detail, such as radiative transfer, photosynthesis, respiration, evapo-transpiration and soil processes [60, 29]. Thus, these models are built to estimate the GPP of terrestrial ecosystems. Such models include the Biome Bio-Geochemical Cycles (BIOME-BGC) model [61], Boreal Ecosystem Productivity Simulator (BEPS) model [62, 63], Lund-Postdam Jena (LPJ) model [64] and Century model (Huang, 2000) [65]. Though ecological process models have a sound scientific basis, these mostly rely on climatic factors forcing variables and model parameterization [29]. These uncertainties lead to differences in the simulation results [46]. Data-driven mathematical and statistical models for ecological productivity quantifies the relationship between environmental factors and ecosystem productivity and can be used to predict responses of environmental factors to the functioning of the environment for better productivity estimation. These methods have been used by Wang *et al*. [66] etc. Machine learning methods have also been used to calculate grassland productivity. According to Mitchell [67], "Machine learning is the study of computer algorithms that allow computer programs to improve through experience automatically. These methods are highly robust and in addition can limit the uncertainties arising due to other factors [46]. Examples of machine learning models include artificial neural networks (ANNs), support vector machines (SVMs), random forests (RFs), and convolutional neural networks (CNNs). A number of studies have proven the excellent performance of machine learning models in estimating GPP. For example, Yang *et al*. [68] used an SVM to predict vegetation GPP. However, machine learning methods require a large amount of input data and many times results are difficult to interpret [46]. These methods also may lack universal applicability because of regional bias [40]. The most existing methods are not sufficiently deep, making the data-mining process shallow [46]. Zhang *et al*. [29] developed a machine learning-based model to simulate leaf area index (LAI) and gross primary productivity (GPP) solely based on meteorological variables and the results showed affirmative simulations between LAI and GPP (Liao *et al*. [46]. The Light Use Efficiency (LUE) model proposed by Monteith [69] is based on the principle of light use efficiency. The main idea of this model involves estimating GPP according to the LUE and absorbed photosynthetically active radiation (APAR) of vegetation. This model also considers the relationship of GPP with the other physiological and ecological processes involved. With the help of wide application of various moderate and high-resolution remote sensing data, LUE models have gradually become the mainstream methods for estimating GPP [46]. This type of models include the Carnegie-Ames-Stanford Approach (CASA) model [70], Vegetation

Photosynthesis Model (VPM) [71], Eddy Covariance-LUE (EC-LUE) model [72] and MODIS GPP standard product (MOD17) [73]. On the basis of using different remote sensing parameters, different LUE models differ in the applicability and purpose [46]. However, geographical variations of vegetation [74], phenology [73] and other factors [75] affect the usefulness of these models. Sun-induced (Solar-Induced) chlorophyll fluorescence (SIF) model is another model which can be used for estimation of ecological productivity. This model is based on calculating the electron transport rate and thus circumventing many of the complexities in conventional modeling. This model is based on absorption of natural light by green plants especially in red and near-infra red regions. Being sensitive to minute changes in photosynthesis, this model can be used find correlationship of GPP at leaf level [76], plant level [77], canopy level [78] and at ecosystem level [79, 80], therefore making it more promising than other methods [46]. However, the results can be meddled by the chlorophyll fluorescence due to reflected light from ground surface, which may account for 1%–5% of the reflected radiant energy in the near-infrared region [46]. The Fraunhofer Line Discrimination method can also be used for estimating ecological productivity. The FLD method relies on the decoupling of reflected and chlorophyll fluorescence emitted radiation by the evaluation of measurements inside and outside the absorption bands [81]. Solar- Induced Fluorescence (SIF) methods mostly involve calculations based on the Fraunhofer Line Discrimination (FLD) algorithm proposed by Plascyk and Gabriel [82]. Although the standard FLD models are simple to operate, however, uncertainties in the values of reflectivity and fluorescence of two adjacent bands affects the accuracy of estimation results [46]. Fortunately some emerging technologies in this field have provided alternative approaches to estimate ecological productivity [79, 83]. These technologies have improved use of physiological and biochemical data to estimate productivity [80, 84]. However, satellite based SIF data, short duration and sensor degradation impacts [85], can also limit use of SIF for long-term GPP estimation. The recently proposed NIRv technique, is defined as the product of NDVI and near-infrared (NIR) reflectance of vegetation. NIRv has a robust physical interpretation, as it relates directly to the number of NIR photons reflected by plants [83]. As a result, it minimizes the effect of different variables on the results. NIRv (Near-Infrared Reflectance of Vegetation) technique compared to many other techniques can better explain GPP flux changes at different time scales. However, certain shortcomings of this method limits its use on a larger scale [86, 87]. Using different methods (mostly on dry weight and /or energy basis), a lot of work has been done to estimate biomass and primary productivity in different grassland types. Even though alternatives to the conventional harvesting methods have been devised [88], the conventional harvesting methods for ecological productivity are still in vogue.

According to Theunissen [89] the effect of both environmental and genetic factors determine the eventual biomass production of a species in an ecosystem. Many researchers have tried to find correlations between different environmental factors with biomass and productivity. Precipitation being a primary climatic determinant for productivity [90], therefore its effect on ecological productivity has been extensively studied. Similarly Parton *et al*. [91] and Peng *et al*. [92] also attributed the role of precipitation and temperature in regulating productivity in grasslands. According to Leith [93] and Long *et al*. [94] tropical ecosystems are more productive on an annual basis than their sub-mountain and mountain counterparts probably because of having more favourable temperature throughout the year. Munshi [120] stated that most of the tropical grasslands exhibit higher efficiency of energy capture (around 1%) as compared to temperate grasslands due to higher proportion of C_4-species. Unlike the tropical grasslands, the temperate and alpine grasslands exhibit a strong seasonality. The growing season in the temperate, sub-alpine and alpine grasslands is restricted, therefore biomass production in general in these grasslands is lower than in tropical ones [95, 96]. Similarly Ram *et al*. [97] found low productivity in high altitude grasslands in Central Himalayas as compared to low altitude ones. However, studies of Rajwar and Ramola [98] revealed that total net primary productivity was higher on higher slope sites than on the lower ones in both east and west mountain grasslands of Utrakashi, Garhwal Himalayas. Dunham [99] reported that primary productivity in perennial grasslands was greater than in annual ones in Mana Pools National Park, Zimbabwe, probably because of extended growing season in the former ones. Reddy [124] using biomass harvest method also related the difference in net primary production between two years to the corresponding difference in rainfall in some grasslands in Guntur, Andhra Pradesh, India. In a grassland studied by Kinyamario and Macharia [112], standing crop varied according to the rainfall period more during the growing season than during dry season. Different species in an ecosystem respond differently to the amount, occasions and type of precipitation. Herben *et al.* [100] found inter-annual variations in biomass production and such variations were largely explained by variations in weather. Sims and Singh [117] reported a linear increase in peak live biomass with the increasing amounts of growing season precipitation up to 450 mm, but at higher values of precipitation, increase in live biomass levelled off in some North American grasslands. Theunissen [89] however, found no correlation between productivity of a species and long-term average rainfall. In an alpine grassland in Himalayas rapid shoot growth was attributed to moisture obtained by snow-melt in April-May [101]. Plant productivity is highly sensitive to and can rapidly increase in response to moderate levels of increased precipitation due to relief of water and nutrient stress [102, 103]. Zhang *et al.* [104] found that the plant biomass and productivity in grasslands is not affected only by present year precipitation but also by previous year precipitation amount and pattern. Grime *et al.* [105] also found decline in grassland biomass in a 5-year experiment by winter heating. Sternberg *et al.* [106] and Kahmen *et al.* [107] showed that experimental drought events reduced biomass productivity. However, these findings were inconsistent with findings of Beierkuhnlein *et al.* [108] and Ma *et al.* [109] who found that warming has no or very limited influence on biomass productivity. Pandey [110] and Sinha *et al.* [111] also related biomass and productivity to seasonality and observed maximum conversion of captured energy into aboveground biomass during the rainy season while the trend was reversed in summer and winter in tropical grassland in India. According to Epstein *et al.* [112], productivity of C_3-species tended to be negatively related to mean annual temperature (MAT), mean annual precipitation (MAP) and positively related to clay in the Great Plains of USA. While production of C_4-short grasses, in general, was positively related to MAT and negatively related to MAP and sand fraction of the soil, whereas C_4-tall grass productivity tended to be positively associated with MAP and sand fraction of the soil, and was highest at intermediate values of MAT. Indirect influences of phenology on productivity could exist due to close associations between phenology and plant functional traits [113]. Biomass generally increased in warmer, wetter and species-rich sites with longer growing seasons [114] probably because of more chances of germination of seeds. Studies of Loydi *et al.* [115] showed that phenology can directly or indirectly affect plant biomass and productivity by means of affecting other phenophases. For example, availability of litter can affect germination. Some workers have also related productivity of an ecosystem to its species diversity and stability. Tilman and Downing [116] reported that primary productivity in more diverse plant communities was more resistant to and recovered more fully from a major drought. The negative effects of moderate drought on productivity may be buffered by increased water use efficiency by plants [117, 118], resulting in low productivity sensitivity. According to Misra and Misra [119] the relationship between dominance and net primary production showed that the concentration of biomass in a limited number of species did not influence the energy capture efficiency of vegetation. The positive correlation between stability and dominance indicated that increase in concentration of biomass in a limited number of species did not lead to stability of community [120]. Perez Corona *et al.* [121] considered the correlations between production and botanical fractions like grasses, legumes and forbs in a semi-arid natural grassland in Central West of Spain and recorded a significant correlation between productivity and the grass group. Likewise Kaushik and Sharma [122] found *Chrysopogon montanus* as the dominant species in respect of productivity in a grassland in Shivalik hills in India. *Themeda triandra* contributed most of the standing crop followed by *Pennisetum mezianus* in a grassland studied by Kinyamario and Macharia [123]. Different types of biotic stresses affect plant biomass and primary productivity [124]. The most important biotic stress is grazing and annual net production was found comparatively higher on un-grazed site than on grazed site [125, 126]. The net primary productivity was 760.5 gm^{-2} yr^{-1} in un-grazed and 1390 $gm^{-2}yr^{-1}$ in grazed plots in an alpine Himalayan grassland [127]. However, Sims and Singh [128] observed no significant difference between seasonal live biomass under grazed and un-grazed treatments in some North American grasslands. In some semi-arid grasslands of Madurai, Tamil Nadu, of the total net primary productivity, 26% was realized as aboveground net productivity and 74% as belowground net productivity in protected areas while in grazed sites aboveground net productivity and belowground net productivity was 39.7% and 60.3% respectively [129].

Various workers have given energy efficiency values in various types of grasslands. Choudhary [130] gave the efficiency of net primary production as 0.283% in a *Dicanthium anulatum* dominated grassland. Munshi [131] observed the energy utilization efficiency during the entire growth period as 0.8114% in a tropical grassland in Bhagalpur, Bihar. Maximum rate of accumulation of live biomass ranged between 0.4 to 6.5 gm^{-2}day^{-1} in some North American grasslands [128]. The average daily productivity was 12.5 gm^{-2} during the rainy season in a grassland dominated by *Dicanthium* sp. [130].

Aboveground biomass (AGB) can be defined as the mass of living and dead plant tissue above the ground. Aboveground biomass is a sensitive indicator of grassland health status, ecosystem function [132], resource quality and ecological degradation [133]. In tropical Indian grasslands, the annual aboveground net production varied between 98 to 3396 gm^{-2} yr^{-1}. The values for the arid to semi-arid grasslands were lower than those for the more humid (high rainfall) grasslands [134]. Reddy [135] estimated a value of 2079 and 1360 gm^{-2} yr^{-1} as aboveground net primary productivity during two consecutive years in a tropical grassland in Guntur, Andhra Pradesh. According to studies of Gupta [136] and Sundriyal [137] the above-ground biomass varied 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 India. In grasslands aboveground live biomass and belowground biomass are the outcome of interplay of different ecological factors [138], among them precipitation [139] and temperature [140] are widely recognized as the most important ones. Therefore climate change is exerting significant pressure on grassland ecosystems, particularly by influencing AGB, thereby threatening both ecosystem stability and biodiversity [141,142]. Correct estimation of above ground biomass (AGB) and its spatial and temporal changes is vital for determining the carbon cycle of grasslands [132]. Appropriate and correct tracking of any change in AGB in grasslands is very important for studying structure, function and the stability of grasslands. Drought was shown to decrease aboveground live biomass by an average of 47% in four different grasslands [142]. Findings of Hossain and Beierkuhnlein [143] showed a significant decrease in aboveground biomass with the increase of growing season temperature, which is consistent with the findings of Weißhuhn *et al*. [144] and Jentsch *et al*. [145] who found that biomass production declined with warming. 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 [146] probably because of increase in favourable growth temperature. However, no detailed studies on the productivity were available along the entire gradient. The studies of Chen *et al*. [147] revealed that warming significantly increased the biomass by prolonging the growing season, which has also positive impacts on aboveground biomass productivity [148]. However, evidence suggesting that higher growing season temperature can lower biomass productivity by reducing water availability and limiting photosynthesis [149] and increasing evapotranspiration [150, 151] also exist. Similarly species diversity also affects aboveground biomass and its productivity. Species diversity and dominance are among the factors influencing aboveground biomass and its productivity. According to Joshi *et al.* [152], 88% of the aboveground live biomass of a high altitude grassland in Garhwal Himalayas was contributed by only 15 plant species and *Carex nubigena* contributed maximum (19%) to aboveground live production. Studies of Vermeer and Berndse [153] and Nie *et al*. [154] showed negative correlations between shoot biomass and species number in the studied grasslands. However, Wang *et al*. [155] found a linear relationship between aboveground biomass and plant species diversity during the initial stage restoration in a degraded grassland. Nie *et al*. [154] also observed that the changing diversity-productivity relationships were driven by changes in species composition of the plant community, given the significant productivity gap between rare and non-rare species. This shows how management practices are important in maintaining grassland productivity, diversity and stability. Kakati and Yadava [155], Karunaichamy and Paliwal [156] and Pradhan and Mohanty [157] found a significant correlation between live shoot biomass and standing crop of chlorophyll. Multiple correlation tests revealed a direct relationship between community energy content and or total chlorophyll content and leaf area index [158]. Laxton *et al.* [159] related increase in biomass with the quality of slit in the soil in loessel grasslands in Canada, while Vermeer and Berndse [153] showed a positive correlation between shoot biomass and nutrient concentration in the soil. Aboveground productivity of *Sporobolus kentrophyllus* (a C_4-species found in grasslands) decreased slightly under elevated CO_2 concentration [160]. Day and Detling [161] recorded higher aboveground live biomass and root mass on urine patches (due to more nutrient concentrations in it) than in the surroundings. The growth dynamics of a grassland in terms of dry matter output was influenced by the difference in rotation time and rate of nitrogen fertilization [162]. In many situations the associated legumes have been found important for primary productivity [163]. Bhandari *et al*. [164] found that above ground dry matter is higher in sites dominated by C4 plants. This is because C_4 grasses are often characterized by high maximum rates of photosynthesis, photosaturation at high light intensities, and high temperature optima for photosynthesis and growth [165]. Increasing relative abundance of C_4 plants would effectively mitigate the negative effects of dryness stress on gross primary productivity in grasslands [66]. Because of such and other eco-physiological variations, constituent species make variable contributions towards standing crop.

The root system of permanent grasslands is of outstanding importance for resource acquisition [166] , making it a very important compartment of grassland ecosystems with respect to both structure and function [167]. Data on belowground biomass production of grassland ecosystems shows their contribution in the range of 40 to 87% of total primary productivity [168]. Like aboveground biomass, belowground biomass is also affected by different environmental factors. According to Crafts-Brandner and Salvucci [169] higher growing season temperature can generate physiological stress, and stimulate root growth instead of shoot growth [170]. Sims and Singh [128] reported that root production increased with decreasing levels of long-term mean annual temperature in some temperate grasslands of North America. Ramakrishnan and Ram [171] recorded belowground net primary productivity more than double of the aboveground net primary productivity in some humid tropical grasslands at Cherrapunji probably due to efficient uptake of nutrients in situations of low soil fertility and poor soil moisture retention in spite of high rainfall. Wu *et al*. [172] and many other researchers found a varied response of livestock grazing to grassland biodiversity and productivity. Nie *et al*. [154] reported that AGB responds positively in grazing grasslands, transiting from negative to positive in mowing grasslands as mowing became more frequent. Aboveground biomass on simulated plots in a semi-arid grassland in Colorado was dominated by *Bouteloua gracilis*, through time and space [173]. According to Sundriyal [174] net production and efficiency of energy storage in aboveground and belowground decreased in free grazing plots compared to plots protected against grazing, which conserved more energy with greater efficiency. According to Singh and Ambasht [175] productivity in the form of shoot biomass was higher in a plot protected completely for two years, followed by the site protected for four years but slightly affected by herbage removal and lowest in the site open for grazing. Belowground biomass was highest in the plot, which was open to the grazing followed by the site protected for four years but slightly affected by herbage removal and least was in the plot completely protected from grazing. According to Joshi *et al.* [127] protected plot after two years yielded an aboveground net production 270.5 gm^{-2} yr^{-1} in an alpine grassland in Garhwal Himalayas, while in grazed plot it was 40.7 $gm^{-2}yr^{-1}$ [176] also recorded maximum biomass production of 768 gm^{-2} in the protected area in October and 308 gm^{-2} in grazed sites in August in a semi-arid grazingland in Tamil Nadu. Total biomass at a protected site in a grassland in Bhagalpur, Bihar varied from a minimum 569.75 mg^{-2} in December to a maximum 1021.44mg^{-2} in October in control plot while at grazed site it varied from a minimum 640.86 gm^{-2} in July to a maximum 987.42gm^{-2} in December [131]. Grazed and ungrazed sites also differ in their maximum biomass (total living, aboveground, and belowground) ; they attain it even in different months. The maximum biomass of 1522gm^{-2} in a protected site as compared to 607 gm^{-2} in a grazed site in a grassland in Tamil Nadu [129]. Grazing significantly decreased aboveground (−38.5%), belowground (−14.7%), and total biomass (−20.6%), but did not significantly change root-shoot ratio, species richness, or evenness [177]. The effects of grazing on plant biomass and diversity depended on climate types and grazing patterns. Specifically, grazing significantly decreased plant total biomass and in dry areas only, but increased root-shoot ratio in wet areas only. Their study also established that growing season and year-long grazing decreased total biomass in grasslands, whereas non-growing season grazing had not changed total biomass. Among livestock types (bulk feeder, concentrate selectors, intermediate feeder or mixed), only intermediate feeder grazing significantly decreased belowground biomass (−16.5%) and total biomass (−25.3%). Heavy grazing significantly decreased belowground biomass (−19.2%), total biomass (−24.3%). However such an effect was not found in case of light and moderate grazing [166]. Karunaichamy and Paliwal [176] also recorded variations in biomass under grazed and ungrazed treatments but got lowest values under both the treatments in February. According to Joshi and Srivastava [178] moderately grazed grassland showed a maximum biomass (1117gm^{-2}) and net annual production (1358gm^{-2}). Positive influence of moderate grazing was further substantiated by the work of Misra and Misra [179] who also recorded higher dry matter production in moderately grazed grasslands in Berhampur, Orissa. However, Sims and Singh [128] got lower values of 212 gm^{-2}yr^{-1} as compared to 236 gm^{-2}yr^{-1} for aboveground net primary productivity in grazed and un-grazed sites respectively. They also found higher root production in grazed sites as compared to un-grazed sites, and approximately 46% and 58% of variability in ungrazed and grazed sites respectively.

Although burning of grasslands is natural, grasslands are burnt in various regions of the world. Whatever the type it affects productivity in the same way, but different intensities, seasons and frequencies of burning affect grasslands differently. According to Pandey [168] biomass of seasonally burnt plots in a grassland could not return to the level of control plot. The live green biomass in general increased significantly in burnt plots with a considerable decrease in belowground biomass. Similarly aboveground net primary productivity is in general higher in burnt sites than in unburnt sites. According to Gupta and Agarwal [181] the highest aboveground live biomass was 330.6 gm^{-2} in the burnt site (in September) as compared to 214.4 gm^{-2} (September) in the control site. Aboveground net productivity was 462± 49gm^{-2} yr^{-1} in unburnt sites while in burnt sites it was 624± 63gm^{-2} in a grassland in Northeast Scotland [182]. According to Pandey [183] primary productivity in a *Dicanthiun annulatum* dominated tropical grassland in India, was more than twice in burnt plot (burnt in January and May) than in a plot burnt only once in May. Productivity of rhizome declined with frequency of burning but increased for shoot and root in a tropical grassland in India [184], but Zhou *et al.* [185] reported that belowground biomass increased in early burnt plot, but decreased in latter burnt one in a grassland in Songnan, China. Summer burning prior to rains showed promising results for higher production and thereby greater recovery rate of biomass as compared to winter burning [184]. Redman *et al.* [186] also observed higher peak biomass in burnt plots than in control plots. Further forb, shrub and graminoid biomass was greater in the unburnt *Festuca* community than in the *Stipa-Agropyron* type. Gupta and Agarwal [181] obtained highest value of 330.6gm^{-2} in September aboveground live biomass in burnt plot; 151.5 to 189.4gm^{-2} in September and November in combined treatment of burning and clipping; 180.2 to 207.0 gm^{-2} in February- March in clipped plot and 214.4gm^{-2} in control plots. While the net aboveground dry matter production of the standing crop was found to be 378.80 gm^{-2} in burnt plots, 616.70 to 664.83gm^{-2} in burnt and clipped (combined treatment) plots, 480.40 to 715.45 gm^{-2} in clipped plots, and 249.25gm^{-2} in control plots. In general clipping decreases standing crop of aboveground live biomass. However, differences occur with different levels and frequency of clipping and interaction with other factors. According to Kaushik and Sharma [187] peak biomass was greater in control plots than in clipped plots in a temperate grassland in Shivalik hills, India. Similar was the case with annual peak biomass. Annual net production was higher in the plot clipped at ground level than that in other two treatments. The peak season belowground biomass was maximum in the control plot during the rainy season. According to Ram [188] late clipping had adverse effect on aboveground live shoot biomass and total herbage yield than in plots clipped in early growing season in an alpine grassland. In a grassland study by Schmid *et al.* [20] higher mowing frequencies led to less ANPP. In mixed effects of burning and clipping, Lamichhane *et al.* [189] found that mean dry biomass was highest in burned-only plots, followed by cut-only plots and cut-and-burned plots in a grassland in Nepal. It can safely be argued that each ecological factor affects both productivity and biomass but their quantum, timing and interaction may have a varied effect in an ecosystem.

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