Received: 03-05-2025; Accepted: 01-06-2025
https://doi.org/10.56024/ispm.75.3ampersand4.2025/79-95

Biomass Dynamics in Grasslands of Manipur

A. Thokchom[1] | M.R. Khan[2] | P.S.Yadava[3]

[1]*Department of Botany, Waikhom Mani Girl's College, Thoubal, 795138, India*
[2]*Department of Botany, Lilong Haoreibi College, Thoubal, 795130, India*
[3]*Department of Life Sciences Manipur University, Chanchipur, Imphal, 795003, India*
E-mail: amrabatithokchom@gmail.com, drriyajuddin_khan@rediffmail.com, yadava.ps1@gmail.com

Author for correspondence:

A. Thokchom
Department of Botany, Waikhom Mani Girl's College, Thoubal, 795138, India

Abstract

The aboveground live biomass in the grasslands of Manipur varied significantly, ranging from 220.74 g m^{-2} in January to 812.89 g m^{-2} in September. The growth patterns of seven dominant species observed at these study sites exhibited distinct variations in their peak biomass values. The amount of standing dead material was recorded as lowest in February, measuring 321.23 g m^{-2}, and peaked in November at 864.14 g m^{-2}. Litter biomass fluctuated between 78.46 g m^{-2} in August and 205.56 g m^{-2} in December, while belowground biomass ranged from 1,074.00 g m^{-2} in June to 1,622.62 g m^{-2} in November throughout the study period. Notably, the highest concentration of belowground biomass was found in the 0-10 cm soil layer, with variations ranging from 73.24% in February to 83.36% in May. The root-to-shoot ratio was observed between 0.73 and 2.05. The analysis of variance for live biomass, standing dead material, litter, and belowground biomass indicated highly significant differences across the various months.

Keywords: Aboveground biomass, Live biomass, Standing dead, Below ground biomass

Introduction

Grasslands, encompassing pastures and rangelands, are among the most significant terrestrial biomes worldwide. These regions typically exist where soil water availability is insufficient to support forests but adequate to sustain grasses as the dominant or at least a prominent form of vegetation. In India, grasslands cover approximately 119,000 km² of the total geographical area. The country is home to around 400 grass species, of which 139 are endemic (Shukla, 1996). Pastures and grazing lands in northeast India represent a mere 0.93% of the total land area (Yadava, 1990). Additionally, rangelands comprise less than 2% of the geographical area in the N.C. Hills and Barak Valley (Shukla, 1996). The low productivity of livestock is a pressing issue, primarily due to inadequate forage and feed resources. Fodder production from all sources is projected to reach 513 million tons of green and 400 million tons of dry forage, respectively. Grazing lands dominated

https://doi.org/10.56024/ispm.75.3ampersand4.2025/79-95

by grasses continue to provide essential feed for livestock growth, development, maintenance, and production. A significant portion of the feed for livestock originates from natural vegetation found on common grazing lands, rangelands, and other non-cultivable areas. In contrast, the quantity of cultivated fodder produced in the country remains minimal.

Biomass dynamics in an ecosystem emphasize a better understanding of the behaviour of vegetation and the quality of organic matter produced in a given interval under prevailing climatic conditions (Gupta et al., 1994). Biomass dynamics in grasslands of India are studied in detail by many researchers (Kumar & Joshi, 1972; Singh & Yadava, 1974; Naik & Mishra, 1977; Pandey, 1978; Shankar et al., 1978; Shankar & Velayudhan, 1979; Trivedi & Mishra, 1979; Trivedi, 1983; Gupta & Mishra, 1983; Misra & Misra, 1984; Kakati, 1985; Tiwari, 1986; Pandey & Singh, 1987; Joshi et al., 1988, 1990; Chaturvedi et al., 1988; Karunai Chamy & Paliwal, 1989; Sah & Ram, 1989; Sundriyal & Joshi, 1990; Sinha et al., 1991; Padhan & Mohanty, 1993; Sah et al., 1994; Gupta et al., 1994; Garkoti & Singh, 1997; Sundaravalli & Paliwal, 1997, 2003; Dhaulakhandi et al., 2000, Chandrashekaran & Swamy, 2002; Gupta & Ratan, 2005; Astapati, 2008). The grasslands of North-Eastern India were studied in detail by Ramakrishnan & Ram (1988), Kakati & Yadava (1990, 2004), Pandey et al. (1993), Ram & Ramakrishnan (1988, 1992), Astapati & Das (2010), Thokchom & Yadava (2016a,b), and Pathak et al. (2018).

The main objectives in this work were to study (i) changes in aboveground live biomass in different months, (ii) the growth pattern of perennial species, (iii) changes in standing dead and litter, (iv) total aboveground biomass, (v) belowground plant biomass, (vi) root/shoot ratio, and (vii) relationship among abiotic and biotic variables in the grassland ecosystem at Khongjom, Manipur.

Material and methods

Site description

Location

The study site, Khongjom, is situated between 24°15' and 24°45' N latitudes and 93°45' and 94°15' E longitudes in the Thoubal district of Manipur, at an altitude of 922 m amsl. Located 35 km from Imphal city, this area is characterized by higher altitudinal grassland and holds historical significance as the site where Manipur inhabitants bravely resisted the British in 1891. Currently, it is integrated into an ecological park. The dominant vegetation includes species such as *Cymbopogon flexuosus, Eulaia fastigiata, Arundinella setosa, Imperata cylindrica, Heteropogon contortus, Dichanthium annulatum*, and *Monocymbium ceresiiforme*.

Climate

The region experiences a monsoonal climate characterized by a warm, humid summer and a cool, dry winter. The average maximum temperature ranges from 22.32°C in January to 30.31°C in May, while the average minimum temperature fluctuates between 4.76°C in January and 22.26°C in July. Relative humidity levels vary, averaging 59.15% in March to 82.64% in July. Rainfall is minimal in January at 13.45 mm and peaks in June at 227.32 mm, leading to an average annual precipitation of 1407.81 mm. The year is divided into three distinct seasons: summer (March to May), rainy (June to October), and winter (November to February).

Soil

The soil in the study area is characterized by a blackish-brown, clayey loam that is alluvial. The soil texture at the site consists of approximately 36.9% sand (± 0.001%), 4.6% silt (± 0.231%), and 52.66% clay (± 0.11%). Additionally, the soil is acidic, with pH values ranging from 5.8 to 6.3.

Biomass estimation

Biomass sampling was conducted from the last week of March 2020 and continued at monthly intervals until March 2021, utilizing a quadrat size of 40 × 40 cm as Milner & Hughes (1968) recommended. The grassland field was divided into three distinct stands, and on each sampling date, biomass was collected from five quadrats in each stand and harvested at ground level with a sharp sickle (Green, 1959; Line, 1959). The harvested plant samples were placed in polythene bags and transported to the laboratory, where they were categorized into live (including live shoots, standing dead, and litter) and dead categories. Live shoots were sorted species-wise while standing dead, and litter was pooled across all species. Litter on the ground was collected by hand during the harvesting of the plots, packed separately in polythene bags, and brought to the laboratory. It was then processed using the flotation method. The materials were stored in paper bags and oven-dried at 80°C to attain a constant dry weight for accurate measurement. For estimating belowground biomass, 10 replicates of monoliths measuring 15 × 15 × 30 cm were excavated monthly from the study site. The excavation depth was limited to 30 cm, as research by Singh & Yadava (1974) indicated that 93% of the total root biomass concentrated within the upper 30 cm of soil in the grassland vegetation. The monoliths were transported to the laboratory, cut into three segments of 10 cm each, soaked in water for 24 hrs, and washed using a fine jet of water through a 32 mm mesh screen. The belowground plant root materials were oven-dried at 80°C until a constant weight was achieved and weighed separately for each depth segment (0-10, 10-20, and 20-30 cm).

Results and discussion

Changes in aboveground live biomass in different months

The total aboveground live biomass exhibited significant variation over the months (Table 1). In March 2020, live biomass measured 256.04 g m^{-2}, gradually increasing to 812.89 g m^{-2} by September 2020. This steady rise in live biomass through April was attributed to the sprouting of new tillers and overall growth, bolstered by favourable conditions heralded by the onset of pre-monsoon rains. This observation suggests that climatic conditions during this period are

Table 1. Changes in the aboveground live biomass (g m^{-2})

Month	mean ± SD
March'20	256.04±63.54
April	371.54±123.32
May	324.95±95.10
June	453.18±154.26
July	610.52±167.76
August	705.33±131.73
September	812.89±168.08
October	716.39±222.56
November	615.11±244.37
December	442.48±123.27
January'21	220.74±130.88
February	258.96±113.81
March	385.58±114.54

conducive to shoot growth (Gupta & Ratan, 2005).

During the rainy season, the rate of increase in live biomass was recorded at 4.27 g m^{-2} day^{-1} in June 2020, 5.08 g m^2 day^{-1} in July 2020, 3.06 g m^{-2} day^{-1} in August 2020, and 3.6 g m^{-2} day-^{1} in September 2020. This indicates that the growth rate of live biomass was significantly higher at the onset of the rainy season, largely due to the vigorous sprouting of rhizomes and the germination of seeds across most species. Notably, the maximum standing crop of live biomass in September 2020 coincided with the peak growth period of vegetation and the flowering of nearly all species, particularly *Imperata cylindrica*, *Heteropogon contortus*, and *Arundinella setosa*. The increases in live biomass for June, July, August, and September 2020 compared to May 2020 were 39.5, 87.9, 117.1, and 150.2%, respectively. Following the cessation of the monsoon, a gradual decline in live biomass was observed from October to December 2020, aligning with the maturation of annual species. The community biomass declined further during the subsequent winter and summer months, reflecting a characteristic trend observed in tropical grasslands (Mall & Billore, 1974; Singh & Yadava, 1974; Gupta & Ratan, 2005). This decline can be attributed to the impending dry period, the maturity of perennial species, the completion of life cycles in annual species, and processes such as seed and leaf shattering and consumption by insects and rodents (Ratliff & Heady, 1962). Consequently, the annual cycle of aboveground live biomass demonstrated a minimum value in January 2021 and reached a maximum peak in September 2020.

The analysis of variance indicates significant variation among the samples collected in different months ($F = 25.77$, $df = 12, 182$; $p < 0.001$). Table 2 summarises the maximum and minimum biomass recorded across various grassland ecosystems in India. Notably, there was substantial variability in aboveground live biomass from site to site within India's grasslands. The minimum biomass values ranged from 10.00 to 1365.00 g m^{-2}, while the maximum values varied from 130.00 to 2637.50 g m^{-2}. Sub-humid grasslands exhibited higher biomass compared to semi-arid regions. The current successional grassland in a humid area reflected biomass accumulation within the ranges seen across Indian grasslands. While its biomass was lower than grasslands in Kurukshetra, Varanasi, Central Himalaya, and Bundelkhand, it still demonstrated significantly higher levels than other regions. Peak biomass in all surveyed areas was observed in September or October, attributable to the onset of the rainy season. Following the maturation of vegetation later in the rainy season, there was a noticeable decline in biomass value as the aerial parts of both perennial and annual species began to dry out, facilitating the transfer of materials to standing dead and litter components. Factors such as botanical composition, geographic location, mean sea level, soil characteristics, and other climatic conditions significantly contribute to the pronounced variation in plant biomass.

Growth pattern of perennial species

Studying the growth patterns of abundant perennial species is essential to comprehend the productivity trends within any ecological community (Singh, 1968). To evaluate the contribution of various species to biomass production growth patterns of seven dominant perennial species (*Cymbopogon flexuosus,*

Table 2. Aboveground biomass (g m^{-2}) and total annual rainfall (mm) in different Indian grasslands

Site	Dominant species	Min.	Max.	Rainfall	Source of data
Jhansi (U.P.)	*Sehima-Heteropogon*	495.65	1407.71	936.00	Shankar et al. (1973)
Kurukshetra (Haryana)	*Dichanthium-Panicum*	105.00	1974.00	799.70	Singh & Yadava (1974)
Varanasi (U.P.)	*Heteropogon-Vetiveria*	340.17	1904.90	1012.00	Singh & Ambasht (1975)
Sagar (M.P.)	*Heteropogon-Dichanthium*	262.40	1010.80	125.00	Jain (1976)
Jhansi (U.P.)	*Chrysopogon fulvus*	256.10	679.39	936.00	Shankar et al. (1978)
Varanasi (U.P.)	*Aristida cyanantha*	775.04	2637.50	1088.60	Pandey (1978)
Ujjain (M.P.)	*Dichanthium annulatum*	344.70	1174.71	1257.00	Mall & Mehta (1978)
Kurukshetra (Haryana)	*Desmostachya bipinnata*	99.30	837.70	799.70	Gupta & Singh (1982)
Jhansi (U.P.)	*Themeda quadrivalvis*	71.59	2121.02	586.60	Gupta & Mishra (1983)
Jhansi (U.P.)	*Heteropogon-Sehima*	32.10	518.70	936.50	Trivedi (1983)
Bundelkhand (U.P.)	*Bothriochloa-Desmostachya*	604.00	1522.00	1169.20	Singh & Srivastava (1984)
Berhampur (Orissa)	*Aristida-Bothriochloa*	322.00	835.00	1080.00	Misra & Misra (1984)
Perhumid Imphal	*Imperata-Borthriochloa*	292.3	1066.9	1351.50	Kakati (1985)
Garhwal Himalaya	*Erianthus-Arundinella*	31.00	343.00	1226.50	Tiwari (1986)
Varanasi (U.P.)	*Dichanthium annulatum*	325.00	1013.00	1100.00	Pandey & Singh (1987)
Temperate Central Himalaya	*Arthraxon lancifolius*	16.00	130.00	2298.00	Chaturvedi et al. (1988)
Varanasi (U.P.)	*Dichanthium annulatum*	1365.00	2503.00	760.00	Pandey (1988)
Cherrapunji (Meghalaya)	*Osbeckia-Arundinella*	281.00	641.00	10372.0	Ramakrishnan & Ram (1988)
Madurai (T.N.)	*Chrysopogon-Heteropogon*	10.00	390.00	575.00	Karunaichamy & Paliwal (1989)
Temperate Central Himalaya	*Cymbopogon-Heteropogon*	40.00	998.00	1787.00	Sah & Ram (1989)
High altitude Himalaya	*Danthonia cachemyriana*	35.00	409.00	1586.00	Ram et al. (1989)
Sambalpur (Orissa)	*Eragrostic-Triumfetta*	73.00	236.00	1345.00	Joshi et al. (1990)
Karnal (Haryana)	*Desmostachya bipinnata*	986.00	1061.00	956.00	Gupta et al. (1990)
Uttarkashi (Uttaranchal)	*Chrysopogon-Digitaria*	122.00	492.00	1674.20	Rajwar & Ramola (1990)
Karnal (Haryana)	*Desmostachya bipinnata*	110.00	820.00	449.00	Sinha et al. (1991)
Garhwal Himalaya	*Capellepedium-Heteropogon*	67.98	321.19	1710.00	Sah et al. (1994)

Site	Dominant species	Min.	Max.	Rainfall	Source of data
Shimla (H.P.)	*Andropogon-Capellepedium*	124.84	358.08	1104.30	Gupta et al. (1994)
Central Himalaya	*Ainsliaena-Polygonum*	900.00	1300.00	2170.00	Garkoti & Singh (1997)
Madurai (T.N.)	*Heteropogon contortus*	33.00	504.00	890.00	Meenakshi-Sundaravalli & Paliwal (1997)
Western Garhwal Himalaya	*Bothriochloa-Stellaria*	15.80	372.60	1606.00	Dhaulakhandi et al. (2000)
Kodayar (T.N.)	Mixed species	684.20	1231.03	2338.00	Chandrashekaran & Swamy (2002)
Madurai (T.N.)	*Heteropogon contortus*	90.00	537.20	1061.00	Sundaravalli & Paliwal (2003)
Bundelkhand (U.P.)	*Iseilema laxum*	727.00	1596.00	1070.00	Gupta & Ratan (2005)
Dorgakona (Assam, N.E. India)	*Imperata cylendrica*	87.45	773.63	2365.00	Astapati & Das (2010)
Imphal, Manipur	*Imperata cylindrica-Sporobolus indicus*	108.33	411.39	1166.80	Thokchom & Yadava (2016a)
Imphal, Manipur	*Imperata cylindrica*	221	625	1408	Thokchom & Yadava (2016b)
Khongjom (Manipur, N.E. India)	*Cymbopogon-Eulalia*	220.74	812.89	1555.80	Present study

Dichanthium annulatum, Eulalia fastigiata, Heteropogon contortus, Imperata cylindrica, Fimbristylis dichotoma, and *Desmodium triflorum*) were examined. The growth changes for each species are presented in log ratios (Singh, 1968).

Figures 1 to 4 illustrate the monthly aboveground live biomass from March 2020 to March 2021. *C. flexuosus* began its growth with the arrival of summer rains, demonstrating a steady increase in live biomass throughout the growing season, reaching a peak in October 2020 before gradually declining until January 2021. The people of Manipur utilize this aromatic plant to create traditional hair lotions. Similarly, the live biomass of *D. annulatum* increased from March 2020 to August 2020, reaching its zenith in November 2020. This species thrives during the wet season, specifically from June to November in India. It exhibits spring growth from February to March but tends to be stemmy (Dabadghao & Shankarnarayanan, 1973). Notably, *D. annulatum* does not perform well in mixed vegetation as it outcompetes other grasses. As a tufted perennial grass, it creates an open turf under grazing conditions and can withstand heavy grazing pressures. The live biomass of *E. fastigiata* exhibited an increase from March 2020 onward, with only a minor decline noted in May 2020, ultimately peaking in October 2020. Following this peak, biomass decreased in the subsequent months, reaching its lowest point in January 2021 due to winter showers, though a slight uptick was observed in February 2021. The winter decline in biomass is attributed to the mortality of plant tillers.

The live biomass of *H. contortus* began to increase in March 2020, peaking in September 2020. This plant exhibited notable growth during the warmer months.

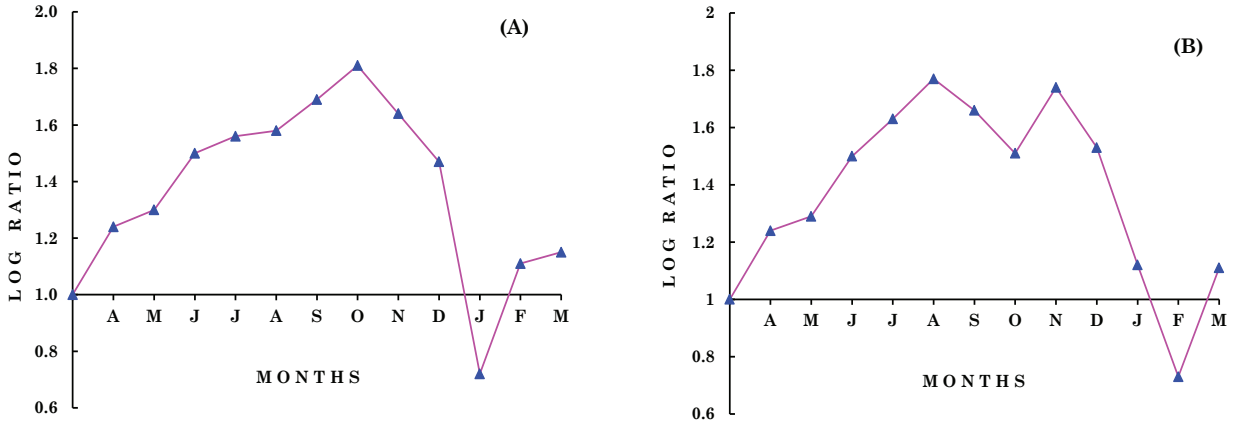

Figure 1. Changes in the live aboveground biomass of *Cymbopogon flexuosus* (A) and *Dichanthium annulatum* (B) in different months throughout the year

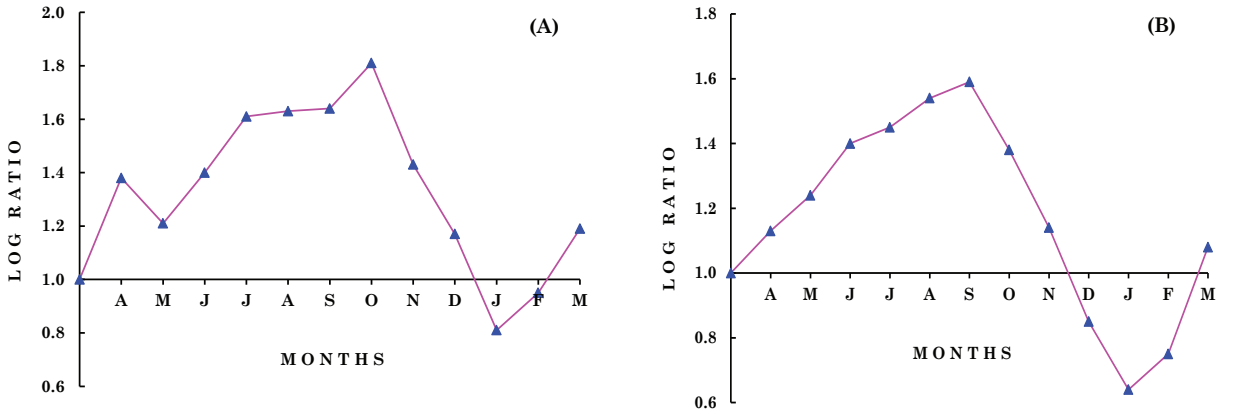

Figure 2. Changes in the live aboveground biomass of *Eulalia fastigiata* (A) and *Heteropogon contortus* (B) in different months throughout the year

While it is palatable during its early vegetative stage, it becomes less preferred by animals as it matures. The reduction in biomass following September 2020 is attributed to the death and shattering of seasonal tillers. This grass is highly regarded as summer fodder in India and can thrive in poor soil conditions. Similarly, the live biomass of *I. cylindrica* increased steadily from March 2020 to September 2020, with only minor declines noted in May and August 2020. After September 2020, a decline was observed until February 2021. The decrease in May 2020 is linked to the degeneration of certain aerial parts following maturation. Additionally, some individuals of this species flower during the rainy season. *F. dichotoma* exhibited the lowest live biomass in March 2020, with increases observed until September 2020, when it peaked before gradually declining. In contrast, *D. triflorum* grows close to the ground surface, reaching its peak live biomass in September 2020 before experiencing a decline. This species

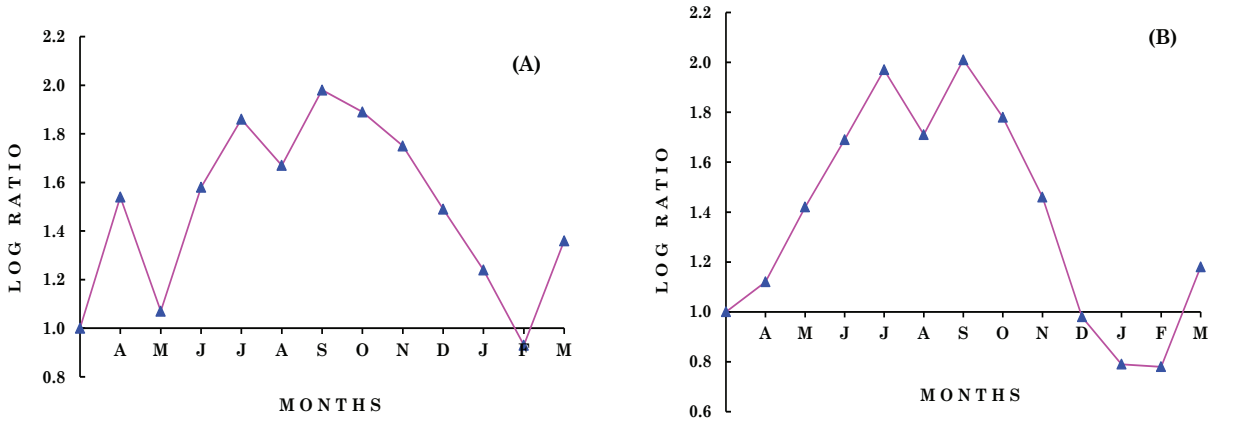

Figure 3. Changes in the live aboveground biomass of *Imperata cylindrica* (A) and *Fimbristylis dichotoma* (B) in different months throughout the year

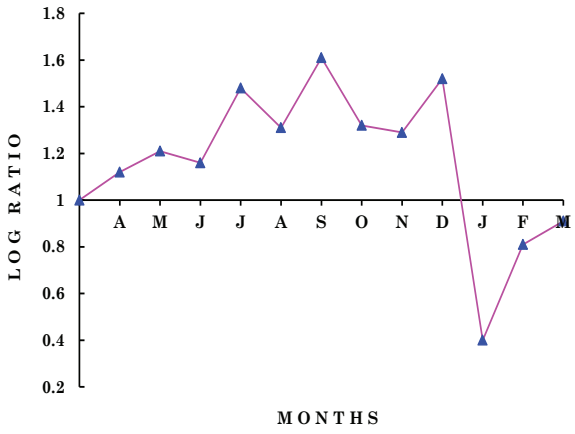

Figure 4. Changes in the live aboveground biomass of *Desmodium triflorum* in different months throughout the year

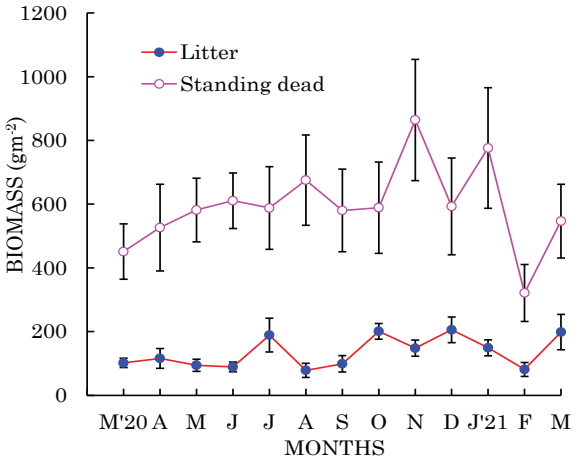

Figure 5. Changes in standing dead and litter in different months throughout the year

displayed inconsistent growth patterns, recording its minimum biomass in January 2021. Notably, it is a nutritious fodder grass that is favoured by cattle.

Changes in standing dead and litter

The amount of standing dead matter fluctuated throughout the study period, with a notable retention of dry matter during the drier months when the biomass of live shoots decreased (Fig. 5). In March 2020, standing dead material was recorded at 451.06 g m^{-2}. This increased in the following months, reaching 610.76 g m^{-2} by June. The subsequent months saw variations, peaking in November at 864.14 g m^{-2}, corresponding with elevated mortality rates of the aerial parts of plants and annual deaths. After this peak, the standing dead material fluctuated in the remaining months. The observed variations in standing dead matter across different months were attributed to the concurrent addition of new biomass and the transition of standing dead matter to litter (Fig. 6). The lowest recorded value of

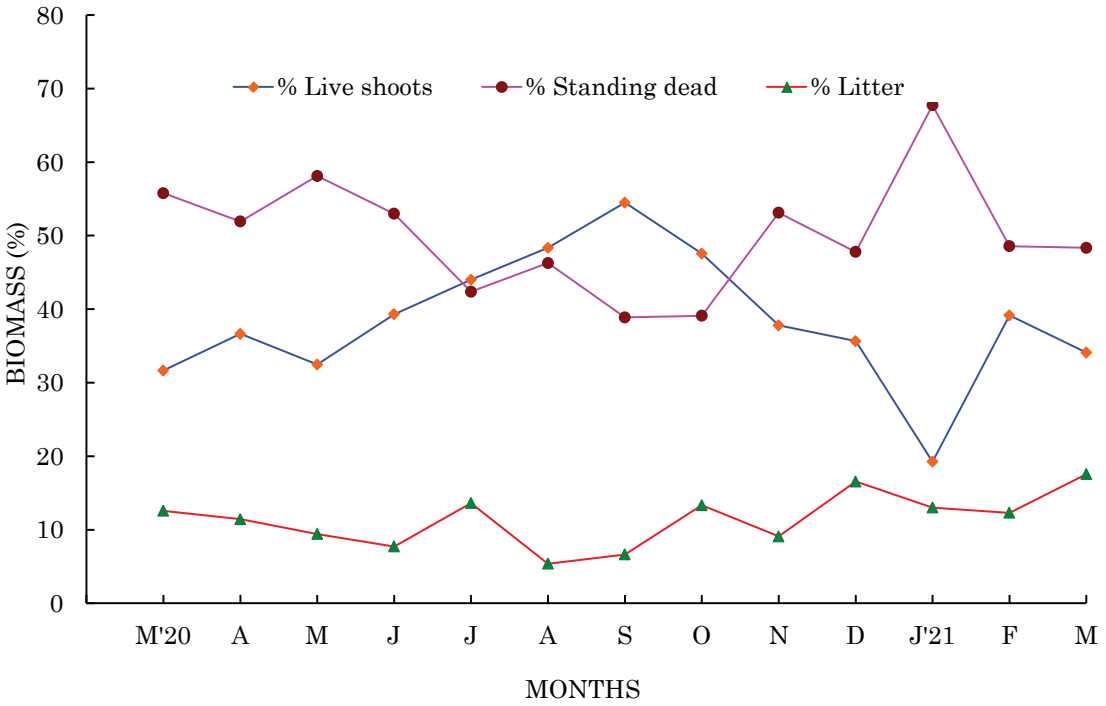

Figure 6. Contribution (%) of live shoots, standing dead and litter in different months throughout the study period

standing dead material was 321.23 g m^{-2} in February 2021. Analysis of variance indicated a significant difference among the samples collected in various months ($F = 14.91$; $df = 12, 184$; $p < 0.001$).

The litter values exhibited notable fluctuations from March 2020 to March 2021. Throughout the study, the minimum litter was recorded in August (78.46 g m^{-2}), while the maximum was noted in December 2020 (205.56 g m^{-2}). The peak accumulation of litter in December can likely be attributed to the increased transfer of standing dead materials to litter, alongside a slow decomposition rate, as the maximum standing dead material was observed in November 2020. Following this peak, litter decreased until February 2021. The winter rains contributed to a significant reduction in litter, dropping it to only 81.35 g m^{-2}. However, there was an increase in litter levels again in March 2021. The variations in litter amounts throughout the year are the cumulative effect of the transfer of standing dead material into litter components and the rate at which litter disappears. Variance analysis revealed a significant difference in samples collected across different months ($F = 37.17$; $df = 12, 182$; $p < 0.001$).

Total aboveground biomass

The total aboveground biomass, comprising live plant material, standing dead matter, and litter, measured 808.74 g m^{-2} in March 2020, reaching its peak of 1627.33 g m^{-2} in November 2020. Subsequently, it experienced a decline, hitting a low of 661.54 g m^{-2} in February 2021. The highest total biomass was observed post-monsoon, with standing dead material and litter significantly elevated during these months (Table 3).

Table 3. Changes in the different components of aboveground biomass throughout the year (g m^{-2} ± SD)

Month	Live biomass	Standing dead	Litter	Total
March'20	256.04±63.54	451.06±86.84	101.64±14.71	808.74
April	371.54±123.32	526.48±136.01	115.96±31.12	1013.98
May	324.95±95.10	581.68±99.77	94.24±19.31	1000.87
June	453.18±154.26	610.76±87.32	89.06±15.19	1153.00
July	610.52±167.76	588.11±129.69	188.95±52.69	1387.58
August	705.33±131.73	675.25±141.82	78.46±22.41	1459.04
September	812.89±168.08	580.06±129.69	98.85±25.53	1491.80
October	716.39±222.56	588.86±143.30	200.76±24.72	1506.01
November	615.11±244.37	864.14±190.37	148.08±25.57	1627.33
December	442.48±123.27	592.98±151.96	205.56±40.08	1241.02
January'21	220.74±130.88	776.38±189.24	149.24±24.93	1146.36
February	258.96±113.81	321.23±89.31	81.35±21.98	661.54
March	385.58±114.54	546.68±115.97	198.48±55.58	1130.74

Belowground plant biomass

The monthly variations in the vertical distribution of belowground biomass across different soil layers were assessed. The study analyzed live and dead roots collected from soil monoliths up to a depth of 30 cm (Table 4). An overall increase in root biomass was not evident, except for a rising trend observed from June to August; however, the biomass value subsequently dropped to 1093.96 g m^{-2} in September. The total root biomass ranged from a minimum of 1074.00 g m^{-2} in June to a maximum of 1622.62 g m^{-2} in November. The lower biomass recorded in June may be attributed to the translocation of reserve food materials to support the growth and development of new tillers in grasses, along with the decomposition of dead belowground materials. November exhibited the highest belowground biomass value at 1622.62 g m^{-2}, followed by a declining trend in the months leading to January when it reached 1110.36 g m^{-2}. The increased biomass observed in April could be due to the early development of absorptive rootlets, which swiftly compensate for translocation (Menaut & Cesar, 1979). Additionally, the slow decomposition rate and fresh growth of roots may contribute to the rise in root biomass observed during April.

The belowground biomass exhibited a decrease with increasing soil depth. Specifically, the root biomass varied from 799.84 g m^{-2} in June to 1276.65 g m^{-2} in April within the 0-10 cm layer. The maximum concentration for this layer ranged from 73.24% in February to 83.36% on March 3, relative to the total belowground biomass. In tropical grassland of Kurukshetra, Singh & Yadava (1974) noted that the greatest concentration of root biomass in the 0-10 cm layer varied between 54.5% in September and 85% in November. Similarly, Naik & Mishra (1974) reported in the grasslands of Ambikapur that in September, a 0-5 cm segment of soil accounted for 58.5% of the underground biomass, with 87.3% recorded at a depth of

Table 4. Distribution of belowground plant biomass (g m^{-2} ± SD) at different soil depths

Month	0-10	10-20	20-30	Total
March'20	1187.51±55.64	174.05±42.83	63.03±20.53	1424.59±516.21
April	1276.65±196.67	220.20±61.49	92.04±40.34	1588.89±552.40
May	901.05±78.10	193.72±40.00	82.58±28.98	1177.35±372.25
June	799.84±84.90	210.02±40.37	64.14±19.55	1074.00±327.88
July	860.21±178.73	198.48±30.41	71.75±16.90	1130.44±365.95
August	944.05±305.14	193.07±52.81	54.29±13.72	1191.41±433.42
September	870.91±172.05	160.48±24.32	62.57±18.97	1093.96±379.07
October	926.57±180.07	185.84±18.56	104.93±25.56	1217.34±389.60
November	1259.34±135.67	292.23±48.31	71.05±22.04	1622.62±531.05
December	1169.94±128.38	205.66±47.33	90.31±19.06	1465.91±498.30
January	855.10±160.52	174.90±16.33	80.36±18.87	1110.36±362.47
February	995.28±134.93	251.81±44.89	111.81±14.48	1358.90±402.29
March'21	889.09±182.42	205.29±18.83	79.87±19.43	1174.25±376.00

0-30 cm. Sims & Singh (1978b) also found that most root biomass was concentrated in the upper layers (0-20 cm). In the temperate grasslands of the USA, they observed that the 0-10 cm layer contributed between 45 to 72% of the total root biomass in ungrazed grasslands and from 43 to 69% in grazed areas. In the 10-20 cm layer, root biomass ranged from 174.05 g m^{-2} in March to 292.23 g m^{-2} in November, while in the 20-30 cm layer, values varied between 54.29 g m^{-2} in August and 111.81 g m^{-2} in February. There was no consistent trend in biomass across all layers; however, some months showed an increasing trend in root biomass within the 10-20 and 20-30 cm layers. The dynamics of belowground biomass differ across various layers, likely influenced by the root growth patterns of the dominant species (Singh & Yadava, 1974).

The various grassland ecosystems in India (Table 5) reveal a significant range in belowground biomass across different regions. The biomass value recorded at the study site in Khongjom, Thoubal, is notably higher than those observed in other Indian grasslands, closely aligning with those from Karnal in Haryana. Specifically, the minimum biomass value ranges from 12 to 1503 g m^{-2}, while the maximum spans from 78 to 2005 g m^{-2} in other regions of the Indian subcontinent. This data demonstrates considerable variability in belowground biomass accumulation, indicating the absence of a distinct trend among adjacent grasslands. The observed differences are likely attributable to variations in botanical composition, regional and geographical factors, climatic conditions, and edaphic characteristics.

Root/shoot ratio

Interspecific and intraspecific factors and environmental conditions significantly influence the relative development of aboveground and belowground plant parts (Numata, 1979). The root-to-shoot ratio and the depth and extent of the root system's penetration play a crucial role in the

Table 5. Belowground biomass (g m^{-2}) and total annual Rainfall (mm) in different Indian grasslands

Site	Dominant species	Min.	Max.	Rainfall	Source of data
Jhansi (U.P.)	*Sehima-Heteropogon*	140.33	466.82	936.00	Shankar et al. (1973)
Ujjain (M.P.)	*Sehima nervosum*	474.00	873.00	1257.00	Mall & Billore (1974)
Kurukshetra (Haryana)	*Dichanthium panicum*	611.00	1167.00	799.70	Singh & Yadava (1974)
Varanasi (U.P.)	*Heteropogon vetiveria*	95.30	318.47	1012.00	Singh & Ambasht (1975)
Jhansi (U.P.)	*Chrysopogon fulvus*	113.08	514.90	936.00	Shankar et al. (1978)
Varanasi (U.P.)	*Aristida cyanantha*	278.78	599.12	1088.60	Pandey (1978)
Ujjain (M.P.)	*Dichanthium annulatum*	324.37	919.50	1257.00	Mall & Mehta (1978)
Kurukshetra (Haryana)	*Desmostachya bipinnata*	672.00	1302.00	799.70	Gupta & Singh (1982)
Jhansi (U.P.)	*Themeda quadrivalvis*	311.93	704.01	586.60	Gupta & Mishra (1983)
Bundelkhand (U.P.)	*Bothriochloa Desmostachya*	653.00	1145.00	1169.20	Singh & Srivastava (1984)
Berhampur (Orissa)	*Arstida-Bothriochloa*	485.00	743.00	1080.00	Misra & Misra (1984)
Perhumid, Imphal	*Imperata-Bothriochloa*	1015.80	1647.7	1351.50	Kakati (1985)
Garhwal Himalaya	*Erianthus-Arundinella*	183.00	722.00	1226.50	Tiwari (1986)
Varanasi (U.P.)	*Dichanthium annulatum*	325.00	1013.00	1100.00	Pandey & Singh (1987)
Temperate Central Himalaya	*Arthraxon lancifolius*	12.00	78.00	2298.00	Chaturvedi et al. (1988)
Varanasi (U.P.)	*Dichanthium annulatum*	643.00	865.00	760.00	Pandey (1988)
Cherrapunji (Meghalaya)	*Osbeckia -Arundinella*	734.00	1088.00	10372.00	Ramakrishnan & Ram (1988)
Temperate Central Himalaya	*Cymbopogon heteropogon*	601.00	975.00	1787.00	Sah & Ram (1989)
High altitude Himalaya	*Danthonia cachemyriana*	307.00	470.00	1586.00	Ram et al. (1989)
Sambalpur (Orissa)	*Eragrostis-Triumfetta*	35.00	118.00	1345.00	Joshi et al. (1990)
Karnal (Haryana)	*Desmostachya bipinnata*	600.00	918.00	956.00	Gupta et al. (1990)
Uttarkashi (Uttaranchal)	*Chrysopogon-Digitaria*	85.00	375.00	1674.20	Rajwar & Ramola (1990)
Karnal (Haryana)	*Desmostachya bipinnata*	785.00	1600.00	449.00	Sinha et al. (1991)

Site	Dominant species	Min.	Max.	Rainfall	Source of data
Garhwal Himalaya	*Capillepedium-Heteropogon*	170.00	785.00	1710.00	Sah et al. (1994)
Madurai (T.N.)	*Heteropogon contortus*	20.00	250.00	890.00	Sundaravalli & Paliwal (1997)
Western Garhwal Himalaya	*Bothriochloa-Stellaria*	1503.00	2005.00	1606.00	Dhaulakhandi et al. (2000)
Bundelkhand (U.P.)	*Iseilema laxum*	454.00	1049.00	1070.00	Gupta & Ratan (2005)
Dorgakona (Assam N.E. India)	*Imperata cylindrical*	370.31	976.00	2365.00	Astapati & Das (2010)
Imphal, Manipur	*Imperata cylindrical-Sporobolus indicus*	1581	2303	1166.80	Thokchom & Yadava (2016a)
Imphal, Manipur	*Imperata cylindrica*	800	1600	1408	Thokchom & Yadava (2016b)
Khongjom, Manipur, N.E. India	*Cymbopogon-Eulalia*	1074.00	1622.62	1555.80	Present study

plant's overall response during dry periods, effectively reducing the transpiring area (Parker, 1969). From March to July 2020, the ratio of belowground to aboveground biomass experienced a decrease, followed by fluctuations, reaching a minimum in September (0.73). This ratio gradually increased until December (1.18) and peaked at 2.05 in February 2021 (Table 6). This data suggests that the root-to-shoot ratio rises during dry periods or xeric conditions. Conversely, as the wet season approaches the ratio declines due to a greater accumulation of aboveground biomass and enhanced upward translocation of assimilates to the shoots. Various grassland studies have reported similar trends (Sims & Singh, 1971; Naik & Misra, 1974; Shankar et al., 1978; Shankar & Velayudhan, 1979; Trivedi & Mishra, 1979).

Relationship between abiotic and biotic variables

The aboveground live biomass was correlated with the total plant density of vegetation, represented by the regression equation: $\hat{Y} = 57.51 + 0.531D$. Here, $\hat{Y}$ denotes the aboveground live biomass (g m^{-2}), and D represents the total vegetation density (shoots m^{-2}). This relationship indicates a strong positive correlation ($r = 0.851$), explaining 72% of the variability in aboveground biomass attributed to changes in density (Fig. 7). The aboveground live biomass was associated with monthly relative humidity (%) through the regression: $\hat{Y} = -653.5 + 15.283H$. Here, $\hat{Y}$ is the aboveground live biomass (g m^{-2}), and H signifies monthly relative humidity (%). This correlation is positive ($r = 0.750$), accounting for 56% of the variability in aboveground biomass due to fluctuations in relative humidity (Fig. 8). Furthermore, the relationship

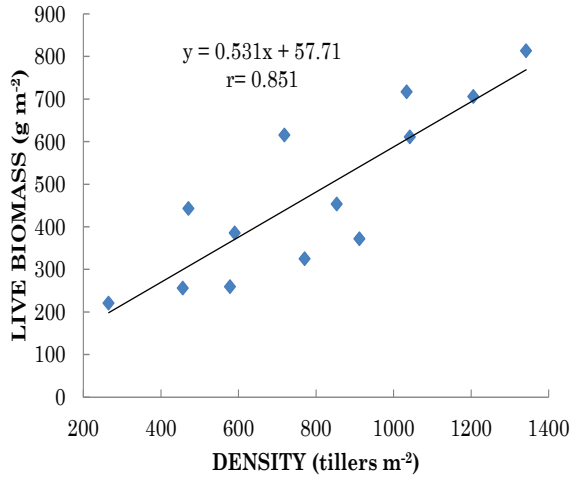

Figure 7. Relationship between vegetation density and live biomass throughout the study period

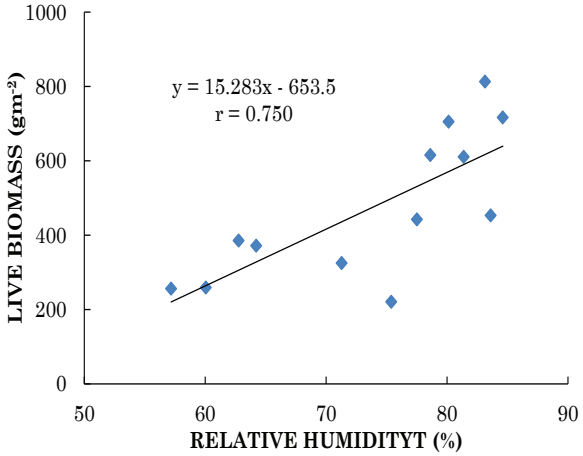

Figure 8. Relationship between vegetation density and live biomass throughout the study period

Table 6. Belowground/aboveground biomass ratio

Month	Biomass (g/m²)		AGB/ BGB ratio
	AGB	BGB	
March'20	1424.59	808.74	1.76
April	1588.89	1013.98	1.57
May	1177.35	1000.87	1.18
June	1074.00	1153.00	0.93
July	1130.44	1387.58	0.81
August	1191.41	1459.04	0.82
September	1093.96	1491.80	0.73
October	1217.34	1506.01	0.81
November	1622.62	1627.33	0.99
December	1465.91	1241.02	1.18
January'21	1110.36	1146.36	0.97
February	1358.90	661.54	2.05
March	1174.25	1130.74	1.04

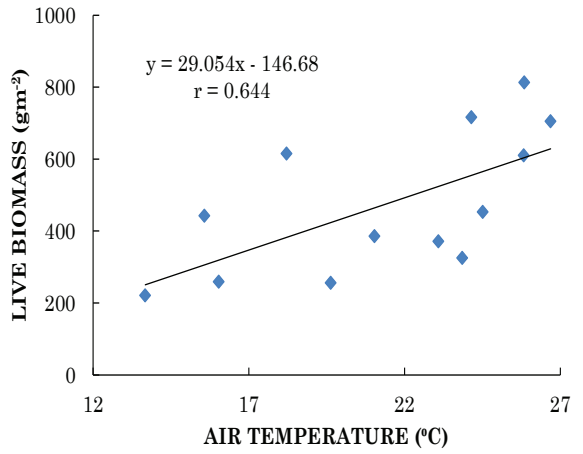

Figure 9. Relationship between air temperature and live biomass throughout the study period

between aboveground live biomass and the monthly air temperature was described by the regression: $\hat{Y} = -146.68 + 29.054T$. Here $\hat{Y}$ is the aboveground live biomass (g m^{-2}), and T indicates the mean monthly air temperature (°C). This correlation also shows a positive association ($r = 0.644$; $p > 0.01$), explaining 42% of the variability in live biomass due to variations in air temperature (Fig. 9). The aboveground live biomass was related to monthly rainfall (mm) following the regression: $\hat{Y} = 0.879 + 367.91R$. In this case, $\hat{Y}$ represents the aboveground live biomass (g m^{-2}), and R

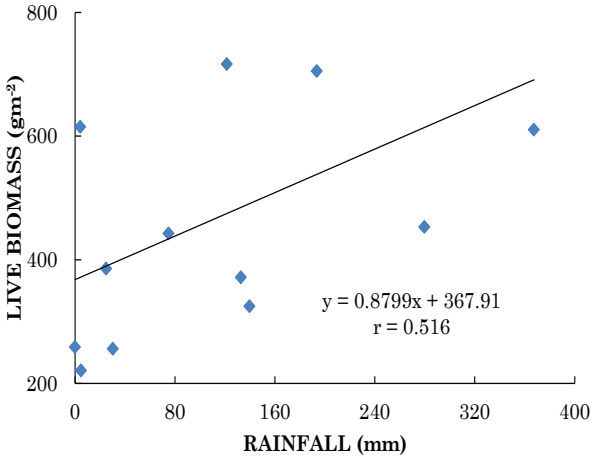

Figure 10. Relationship between rainfall (mm) and live biomass throughout the study period

is the mean monthly rainfall (mm). The relationship shows a positive correlation (r = 0.516), explaining 26% of the variability in aboveground biomass as influenced by rainfall (Fig. 10).

Conclusions

Seasonal variation significantly influenced the biomass dynamics of the grassland ecosystem in Manipur. The aboveground live biomass steadily increased from March 2020, reaching its maximum value in September. An analysis of the growth patterns of seven species present at the study site revealed distinct peaks in biomass. *Cymbopogon flexuosus, Heteropogon contortus, Fimbristylis dichotoma*, and *Desmodium triflorum* exhibited maximum growth during the rainy season. In contrast, *Dichanthium annulatum* and *Eulalia fastigiata* peaked in the winter season. *Imperata cylindrica* presented a unique pattern, with two peaks occurring during the summer and rainy seasons. Consequently, the variation in overall live biomass was mirrored in the growth and contributions of these dominant species. Standing dead biomass was minimal in February but reached its peak in November. Similarly, litter biomass was at its lowest in February and highest in December. Belowground biomass ranged from 1,074.00 g m^{-2} in June to 1,622.62 g m^{-2} in November, with approximately 73.24 to 83.36% of the total belowground biomass concentrated in the 0-10 cm layer. The aboveground live biomass positively correlated with total vegetation density, relative humidity, mean monthly air temperature, and rainfall. The root/shoot ratio was highest in winter, followed by summer and the rainy seasons, indicating that cooler and drier conditions favour the greater accumulation of belowground biomass in grasslands.

References

Astapati AD & Das AK 2010. Biomass and net primary production in an *Imperata* grassland of Barak Valley Assam, North East India. International Journal of Ecology and Environmental Science, 36(2-3): 147-155. https://nieindia.org/Journal/index.php/ijees/article/view/34/32

Chaturvedi OP, Saxena AK & Singh JS 1988. Structural and functional analysis of grazing land under pine forest in Central Himalaya. Acta Oecologica, 9: 167-178.

Chandrashekaran S & Swamy PS 2002. Biomass, litterfall and aboveground net primary productivity of herbaceous communities in varied ecosystems at Kodayar in the Western Ghats of Tamil Nadu. Agriculture Ecosystems and Environment, 88: 61-71. https://doi.org/10.1016/S0167-8809(01)00162-1

Dhaulakhandi M, Rajwar GS & Kumar P 2000. Primary productivity and system transfer functions in alpine grassland of Western Garhwal Himalaya. Tropical Ecology, 41: 99-101.

Garkoti SC & Singh SP 1997. Structure and function of herbaceous vegetation in high mountains of Central Himalaya. Tropical Ecology, 38: 153-156.

Green JO 1959. The measurement of herbage

production. Pp. 62-68. In: Jvins JD (Ed.). The Measurement of Grassland Productivity, Butterworths Scientific Publications, London.
Gupta B, Singh R & Verma RK 1994. Biomass fluctuations in grazinglands around Shimla, Himachal Pradesh. Indian Forester, 120: 488-499.
Gupta RK & Ratan N 2005. Biomass dynamics, net primary production and turnover rate of grassland community in Bundelkhand region (U.P.). Bulletin of National Institute of Ecology, 16: 87-94.
Gupta SR & Singh JS 1982. Influence of floristic composition on the net primary production and dry matter turnover in a tropical grassland. Australian Journal of Ecology, 7: 363-374. https://doi.org/10.1111/j.1442-9993.1982.tb01311.x
Gupta SR & Mishra GP 1983. Seasonal variation in ground biomass net primary productivity and dry matter dynamics in a *Themeda quadrivalvis* type of grassland community at Jhansi, India. International Journal of Ecology and Environmental Science, 9: 123-132.
Gupta SR, Sinha A & Rana RS 1990. Biomass dynamics and nutrient cycling in a sodic soil. International Journal of Ecology and Environmental Science, 16: 57-70.
Jain SK 1976. Aboveground phytomass and net community productivity in some tropical (sub-humid) grass lands at Sagar (M.P.). International Journal of Ecology and Environmental Science, 2: 33-41.
Joshi SK, Pati DP & Behera N 1990. Primary production of herbaceous layer in a tropical deciduous forest in Orissa, India. Tropical Ecology, 31: 73-83.
Joshi SP, Raizada A & Srivastava MM 1988. Net primary productivity of a high altitude grassland in Garhwal Himalaya. Tropical Ecology, 29: 15-20.
Kakati LN 1985. Structure and functioning of the Grassland Ecosystem of Manipur. Ph.D. Thesis, Manipur University, Imphal, Manipur, India.
Kakati LN & Yadava PS 1990. Seasonal changes in chlorophyll and carotenoids contents in a grassland ecosystem at Imphal. Tropical Ecology, 31: 82-88.
Kakati LN & Yadava PS 2004. Phenology and seasonality in a subtropical grassland ecosystem at Imphal (Manipur), India. The Ekologia, 2: 89-96.
Karunaichamy KSTK & Paliwal K 1989. Primary productivity and transfer dynamics of grazing lands at Madurai, Southern India. Tropical Ecology, 30: 111-117.
Kumar A & Joshi MC 1972. The effect of grazing on the structure and productivity of vegetation near Pilani, Rajasthan, India. Journal of Ecology, 60: 665-675. https://doi.org/10.2307/2258558
Line C 1959. The value of herbage estimates in animal production experiments. Pp. 71-78. In: Ivins JD (Ed.). The Measurement of Grassland Productivity, Butterworths Scientific Publications, London.
Mall LP & Mehta SC 1978. The grassland fire. An ecological study. Pp. 291-297. In: Singh JS & Gopal B (Eds.). Glimpses of Ecology. International Scientific Publishers, Jaipur, India.
Mall LP & Billore SK 1974. Dry matter structure and its dynamics in *Sehima* grassland community. 1. Dry matter structure. Tropical Ecology, 40: 430-432.
MeenakshiSundaravalli V & Paliwal V 1997. Dry matter production and nitrogen dynamics in the semi-arid grasslands of Madurai, India, Tropical Ecology, 38: 81-86.
MeenakshiSundaravalli V & Paliwal K 2003. Effect of fire on vegetation composition and primary production of grazing lands in the semi arid region of Madurai. International Journal of Ecology and Environmental Science, 29: 239-243.
Milner C & Hughes RE 1968. Methods for the Measurement of Primary Production of Grassland. Blackwell Scientific Publications, Oxford and Edinburg. 70 pages.
Misra MK & Misra BN 1984. Biomass and primary production in an Indian grassland. Tropical Ecology, 25: 239-247.
Naik ML & Mishra GP 1977. Ecological studies of some grasslands at Ambikapur III. Net community productivity and efficiency of the grasslands. Tropical Ecology, 18: 52-59.
Numata M 1979. Primary producers in meadows. Pp.127-138. In: Coupland RT (Ed.). Grassland Ecosystem of the World. IBP 18. Cambridge University Press, Cambridge.
Padhan S & Mohanty RK 1993. Aboveground biomass, primary production and chlorophyll content of grassland exposed to steel plants waste. Tropical Ecology, 34: 93-101.
Pandey AN 1988. Short-term study of recovery of a tropical grassland following seasonal burning. Tropical Ecology, 29: 159-170.
Pandey HN & Singh RN 1987. Structure and function in early successional communities on an abandoned field at Varanasi, India. Tropical Ecology, 28: 92-100.
Pandey HN, Tripathi RS & Shankar U 1993. Nutrient cycling in an excessively rainfed subtropical grassland at Cherrapunji. Journal of Bioscience, 18: 395-406. https://doi.org/10.1007/BF02702997

Pandey TN 1978. Seasonal variation in the biomass and productivity in a protected grassland of the Chakia Forest, Varanasi. Indian Journal of Ecology, 5: 37-42.
Parker J 1969. Drought resistance mechanisms. Pp. 195-234. In: Kozlowski, TT (Ed.). Water Deficits and Plant Growth. Academic Press, New York.
Pathak K, Nath AJ, Das AK & Bhar M 2018. Litter dynamics in *Imperata cylindrica* grassland under culturally managed system in North East India. Journal of Tropical Agriculture, 56(2): 99-106. https://jtropag.kau.in/index.php/ojs2/article/download/593/464
Rajwar GS & Ramola VC 1990. Variations in net primary production of east and west facing slope montane grasslands of Uttarkashi, Garhwal Himalaya. Indian Forester, 116: 717-722.
Ram J, Singh JS & Singh SP 1989. Plant biomass, species diversity and net primary production in a central Himalayan high altitude grassland. Journal of Ecology, 77: 456-468.
Ramakrishnan PS & Ram SC 1988. Vegetation, biomass and productivity of seral grasslands of Cherrapunji in north-east India. Vegetatio, 74: 47-53. https://www.jstor.org/stable/20038247
Ratliff RC & Heady HF 1962. Seasonal changes in herbage weight in an annual grass community. Journal of Range Management, 15: 146-149. http://dx.doi.org/10.2307/3894914
Sah VK & Ram J 1989. Biomass dynamics, species diversity and net primary production in a temperate grasslands of Central Himalaya, India. Tropical Ecology, 30: 294-302.
Sah VK, Saxena AK & Singh V 1994. Seasonal variation in plant biomass and net primary productivity of grazinglands in the forest zone of Garhwal Himalaya. Tropical Ecology, 35: 115-131.
Shankar V, Shankarnarayan KA & Rai P 1973. Seasonal variation in composition, standing crop and net production in *Sehima-Heteropogon* grassland at Jhansi, India. Tropical Ecology, 14: 238-257.
Shankar V, Velayudhan KC & Kanodia KC 1978. Primary productivity, compartment transfer and system transfer functions in *Chrysopogon fulvus* grassland. Annals of Arid Zone, 17: 30-41. https://epubs.icar.org.in/ejournal/index.php/AAZ/article/view/64796/
Shankar V & Velayudhan KC 1979. Primary productivity, compartment transfer and system transfer functions in *Iseilema laxum* grassland. Annals of Arid Zone, 18: 143-152. https://epubs.icar.org.in/ejournal/index.php/AAZ/article/view/65251
Shukla U 1996. Grasses of North Eastern India. Scientific Publishers. Jodhpur, India.
Sims PL & Singh JS 1971. Herbage dynamics and net primary production in certain ungrazed and grazed grasslands in North America. Pp. 59-124. In: French NR (Ed.). Preliminary Analysis of Structure and Function in Grasslands. Range Science Department Science Series, n° 10, Colorado State University, Colorado, USA.
Singh JS & Yadava PS 1974. Seasonal variation in composition, plant biomass and net primary productivity of a tropical grassland at Kurukshetra, India. Ecological Monographs, 44: 351-378. https://doi.org/10.2307/2937034
Singh UN & Ambasht RS 1975. Biotic stress and variability in structure and organic (net primary) production of grassland communities at Varanasi, India. Tropical Ecology, 16: 86-95.
Singh UN & Srivastava A 1984. Variation in species composition, herbage production and dry matter dynamics in *Bothriochloa-Desmostachya* grassland community in Bundelkhand region. Indian Journal of Range Management, 5: 1-9.
Sinha A, Rana RS & Gupta SR 1991. Growth patterns, net primary production and energy transfers in two grassland communities of sodic soils. Tropical Ecology, 32: 105116.
Sundriyal RC & Joshi AP 1990. Effect of grazing on standing crop, productivity and efficiency of energy capture in an alpine grassland ecosystem at Tungnath (Garhwal Himalaya), India. Tropical Ecology, 31: 84-97.
Thokchom A & Yadava PS 2016a. Changes in the seasonal cycle of carbon stocks and fluxes due to fires in grassland ecosystem of Manipur, Northeast India, Current Science, 110(6): 1088-1094. https://www.jstor.org/stable/24907878
Thokchom A & Yadava PS 2016b. Carbon dynamics in an *Imperata* grassland in Northeast India. Tropical Grasslands, 4: 19-28. https://dx.doi.org/10.17138/TGFT(4)19-28
Tiwari SC 1986. Variations in net primary production of Garhwal Himalayan grasslands. Tropical Ecology, 27: 166-173.
Trivedi BK 1983. Architecture and aboveground production of a grassland community at Jhansi (India). International Journal of Ecology and Environmental Science, 9: 111-122.
Trivedi BK & Mishra GP 1979. Seasonal variation in species composition, plant biomass and net community productivity of two grasslands in *Schima-Dichanthium* cover type. Tropical Ecology, 20: 114-125.
Yadava PS 1990. Savannas of north-east India. Journal of Biogeography, 17: 385-394. https://doi.org/10.2307/2845367