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Net Primary Productivity and Transfer Dynamics in Kashmir Himalayan Grasslands

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ABSTRACT

In view of being an important process in ecosystems and of great significance to ecological studies, net primary productivity, together with accumulation of plant dry matter and its transfer dynamics, was studied in two grasslands occurring at elevations of 1600 m (low elevation grassland) and 1950 m above mean sea level (high elevation grassland). Thirty eight species occurred at the low elevation grassland and 11 species were recorded at the high elevation grassland. Maximum aboveground live plant biomass in low elevation grassland was 422.00 g m^{-2} and the same in high elevation grassland was 2189.30 g m^{-2}. Peak values of standing dead material in the two grasslands were 558.6 g m^{-2} and 2377.2 g m^{-2}, respectively. The litter mass in the low elevation grassland ranged from a low of 156 g m^{-2} to a high of 1111 g m^{-2} while as the corresponding values in the high elvation grassland were 840 g m^{-2} and 1590 g m^{-2}, respectively. Belowground drymass was also higher (5016.50 g m^{-2}) in high elevation grassland compared to low elevation grassland wherein peak belowground drymass was 1691.50 g m^{-2}. Aboveground Net Productivity (ANP), Belowground Net productivity (BNP) and Total Net Productivity (TNP) values in the low elevation grassland were 1467.76 g $m^{-2}y^{-1}$, 1940.00 g $m^{-2}y^{-1}$, and 3408.21 g $m^{-2}y^{-1}$, respectively. The corresponding values in the high elevation grassland were 3088.69, 6072.50 and 9161.19 g $m^{-2}y^{-1}$. Of the total TNP, 43% and 34% were transferred to ANP in low- and high elevation grasslands, respectively. About 57% and 67% of TNP was transferred to BNP in the two grasslands. The turnover rates of aboveground live biomass and belowground biomass in the low elevation grassland were 3.48 and 1.58, respectively and the corresponding values in the high elevation grassland were 1.41. and 1.21.

Key Words: Elevation Gradient, Grasslands, Plant Biomass, Primary Production, System Transfer Function

INTRODUCTION

Net primary production (NPP), that quantifies the net carbon fixed by vegetation, is a principal indictor of ecosystem health, resource utilization, and biospheric carbon fluxes (Cao et al. 2004). Since it is an important process in ecosystems that influences nutrient cycling, food web structure, disturbance regimes, species abundances, community structure, and other ecosystem functions (Perry 1994, Hansen et al. 2000), NPP is of great importance to ecological studies, natural resource management, and estimates of terrestrial carbon sink (Luo et al. 2004).

Net primary production is highly variable in space and time. Spatial variations of NPP are related to factors such as climate, vegetation distribution, and land use across the plane from local to global scales (Cao et al. 2004). Temporal changes in NPP are linked to both 'fast' process (e.g. diurnal and seasonal variability in weather and the consequent physiological responses) and 'slow' processes (e.g. changes in atmospheric composition, climatic changes, and ecosystem redistribution). While a great deal has been learned about NPP levels and controlling factors within and between ecosystems (Bormann et al. 1970; Graumlich et al. 1989), relatively few studies have quantified spatial variation in NPP across landscapes. Knowledge of spatial patterns in NPP may enrich our understanding of the role of NPP in driving ecosystem and landscape function. Elevation, which often represents a complex gradient in climate, soils, and topography (Whittaker 1975), is known to influence NPP. Several authors, in fact, have found that NPP varied across elevation gradients in association with temperature, precipitation, vapour pressure deficit, topographic position, and fire history (Whittaker and Niering 1975, Singh et al. 1994, Raich et al. 1997). Similarly, local and regional spatial patterns in NPP have been correlated with climatic, topographic, soil, and land use factors (Burke et al. 1991, 1997, Knapp et al. 1993).

The spatial pattering of NPP may have particularly strong consequences for ecological processes and organisms whose dynamics depend upon flows over a landscape. For example, the population dynamics of some organisms may depend upon the spatial patterning of NPP.

High levels of spatial variation due to variable topography, climate, and soils is very evident in the Kashmir Himalayan region and consequently it habours diverse terrestrial and aquatic ecosystems. Grasslands, the dominant ecosystem of the region, occur at different altitudes ranging from 1500 m to 3000 m above sea level. Except for the climax high Himalayan meadows, these grasslands have originated either due to deforestation or abandoned cultivation (Blasco 1983; Misra 1983, Singh et al. 1985). The grasslands occurring at low altitudes (1500 meters) constitute the main feeding grounds for livestock of the inhabitants and hence are under considerable biotic pressure. Notwithstanding the importance of such grasslands, very scarce ecological information is available about them and hence the present studies on dry matter production and transfer dynamics of representative protected grasslands occurring at two elevations were conducted in the Kashmir Himalaya, India. Significance of such studies in understanding the functioning of ecosystems has been stressed by Lauenroth and Whitman (1977) and consequently over the years a number of studies on vital functional attributes of plant biomass and net primary production have been conducted on central and eastern Himalayan grasslands (Bisht and Gupta 1985, Ramakrishnan and Ram 1988, Ram et al. 1989, Sah and Ram 1989, Sundriyal and Joshi 1990, Sundriyal 1992, Bawa 1995, Joshi 1995) but no such attempt has been made so far to study the Kashmir Himalayan grasslands. Hence a detailed analysis of the dry matter accumulation and disappearance in producer sub-system compartments, primary productivity and transfer dynamics was carried out with the objective of obtaining reliable baseline data about the dry matter dynamics and primary productivity of these grasslands which has assumed urgency in view of excessive exploitation of these grasslands in the region.

MATERIALS AND METHODS

Study Area

The present study was undertaken in and around Dachigam-Telbal catchment area which lies between 34° 04′ to 34° 14′ N latitude and 74° 48′ to 75° 85′ E longitude covering an altitudinal range of 1600 to 4250 m above mean sea level. The catchment is a part of the great Zanskar range which itself is a branch of western Himalayas.

The catchment encompasses an area of about 221 sq. km, the major portion of which (141 sq. km) has been converted into National Park in the recent past to give protection to the last viable population of an endemic Hangul deer (*Cervus elaphus hanglu* Wagner) of the region. The National Park at Dachigam is roughly rectangular in shape with an approximate length and breadth of 22.5 and 8 km respectively. Two steep ridges, one arising from Harwan reservoir with peaks from 2600 to 3000 m above mean sea level and another in the east of New Theed village rising above 4200 m a.m.s.l, form the natural boundary of the park. The rest of the catchment, known as Telba1 catchment, with an area of about 80 sq. km is a part of the latter steep ridge rising in the east of new Theed village. Dachigam National Park is drained by Dachigam Nallah while the Telbal catchment is drained by Dara Nallah both joining downstream to form the Telbal Nallah, the main feeding source for the famous Dal Lake.

The low elevation grassland (LEG) occurs at an altitude of 1600 m whereas the high elevation grassland (HEG) lies at 1950 m altitude. Both grasslands were free from any grazing for the past 15 years and had similar aspect. The grasslands had a flat topography and were well drained. The climate is sub-Mediterranean with four distinct seasons, viz., spring (March-May), summer (June-August), autumn (September-November) and winter (December-February).

Floristics

During the study period (April 2003 to March 2004), the experimental sites at low as well as high altitude were surveyed in the last week of each month. Standard taxonomic procedures were followed for collection and further processing of the plant specimens (Bridsen and Forman 1992). The processed plant specimens were identified with the help of relevant taxonomic literature (Stewart 1972).

Dry Matter Production

Biomass and primary productivity in producer sub-compartments of the two grasslands were estimated on monthly basis following Milner and Hughes (1968), and Singh and Yadava (1974). For estimating the aboveground primary productivity, 50 x 50 cm quadrats were used (Ram et al. 1989). The plant material clipped at the ground level was separated into live and standing dead components. Litter from four replicate quadrats was collected and further processed by floatation method (Tiwari 1986). For belowground biomass, monoliths of the size 20 x 20 x 30 cm from four replicate quadrats were dug out. Monoliths were then washed with a fine jet of water using successively 2mm and 0.5 mm mesh screens (Ram et al. 1989; Karunaichamy and Paliwal 1989). All the samples of each producer sub-system were then oven dried at 80^oC to constant weight. The oven dried samples were then weighed on a top loading electronic balance.

Aboveground net primary productivity (ANP) was calculated as the sum of positive changes in aboveground live biomass; also added were the positive changes in standing dead (SD) and litter (L) compartments. Belowground net primary productivity (BNP) was estimated as the summation of positive changes in the belowground biomass on successive sampling dates (Singh and Yadava 1974). Total net primary productivity (TNP) was calculated as the sum of ANP and BNP (Bawa 1995).

System Transfer Functions

The transfer of biomass between different producer sub-compartments was calculated following the methods of Singh and Yadava (1974) and Sims and Singh (1978) as outlined below:

i) Transfer of live aboveground biomass to standing dead compartment was calculated by the summation of the positive changes in the standing crop of standing dead plant biomass on successive sampling dates.

ii) The transfer of standing dead to litter compartment was calculated by the summation of negative changes in the standing crop of standing dead material on successive sampling dates. The decrease in the amount of standing dead material within a sampling interval represented transfer to litter compartment.

The litter disappearance (LD) was estimated as:

LD = (Initial litter biomass + Litter productivity) – (Final litter biomass).

iii) The disappearance of belowground biomass (RD) was calculated by the summation of significant negative changes in the belowground biomass on successive sampling dates. Total disappearance (TD) was the sum of LD and RD.

Turnover rates for aboveground and belowground plant biomass were calculated using the formulae given by Dahlman and Kucera (1965).

Total input from any compartment of the system was calculated as the sum of initial biomass in the compartment and net productivity of the compartment while total output of any compartment of the system was calculated as the sum of the biomass transferred from that very compartment to the subsequent compartment and biomass in that compartment at the end (Singh and Yadava 1974).

RESULTS

Floristic Composition

A total of 48 species were recorded from the two grasslands; 38 species were present in the low elevation site and only 11 in the high elevation grassland (Table 1). These plant species could be divided into three functional groups; there were 9 graminoids (23.7%), 7 legumes (18.4%) and 22 non-leguminous forbs (57.9%) in the low elevation grassland (Table 2) whereas only one graminoid (9.1%), 3 legumes (27.3%) and 7 (63.6%) non-leguminous forbs occurred in the high elevation grassland (Table 2). Species richness varied from 3 species in January to 26 species in May in the LEG and the same ranged from 1 species in January to 10 species in August in the HEG (Table 2).

Dry Matter Production

Forage production was estimated in terms of biomass (phytomass) and productivity. The salient features of biomass accumulation in the producer sub-system and primary productivity of the grasslands studied during the study period are summarized below:

Biomass

Biomass in the aboveground live, standing dead, litter and belowground compartments of the producer sub-

Table 1. List of the species growing in the low elevation (LEG) and high elevation (HEG) grasslands.

Name of the species	Family	LEG	HEG
Aegilops tauschii Cosson	Poaceae	+	-
Arenaria serpyllifolia L.	Caryophyllaceae	+	-
Artemesia absinthium L.	Asteraceae	-	+
Asparagus filicinus Ham.	Liliaceae	-	+
Bidens cernua L.	Asteraceae	-	+
Bothriochloa ishaemum Keng	Poaceae	+	-
Bromus japonicus Thunb. ex Murr.	Poaceae	+	-
Capsella bursa-pastoris Medic.	Brassicaceae	+	-
Cichorium intybus L.	Asteraceae	+	-
Convolvulus arvensis L.	Convolvulaceae	+	-
Crepis sancta Babc.	Asteraceae	+	-
Cynodon dactylon Pers.	Poaceae	+	-
Daucus carota L.	Apiaceae	+	-
Erigeron canadensis L.	Asteraceae	+	-
E. multicaulis Wall. ex DC.	Asteraceae	-	+
Erodium cicutarium L'Hert. ex Aiton	Geraniaceae	+	-
Euphorbia helioscopia L.	Euphorbiaceae	+	-
Hackelia macrophylla I.M.J	Boraginaceae	-	+
Hordeum vulgare L.	Poaceae	+	-
Hypericum perforatum L.	Hypericaceae	+	-
Indigofera heterantha Wall. ex Brand	Fabaceae	-	+
Lespedeza cuneata G.Don.	Fabaceae	+	-
L. elegans Camb.	Fabaceae	-	+
Lithospermum arvense L.	Boraginaceae	+	-
Lolium temulentum L.	Poaceae	+	-
Lotus corniculatus L.	Fabaceae	+	-
Medicago minima Grufb.	Fabaceae	+	+
Medicago polymorpha Bartal	Fabaceae	+	-
Nepeta cataria L.	Lamiaceae	+	-
Oenothera glazioviana Raven	Onagraceae	+	-
Oxalis corniculata L.	Oxalidaceae	+	-
Plantago lanceolata L.	Plantaginaceae	+	-
Poa annua L.	Poaceae	+	-
Poa bulbosa L.	Poaceae	+	-
Poa pratensis L.	Poaceae	+	-
Ranunculus arvensis L.	Ranunculaceae	+	-
Rosa macrophylla Lindl.	Rosaceae	-	+
Scandix pectin-veneris L.	Fumariaceae	+	-
Sisymbrium loesellii L.	Brassicaceae	+	-
Sium latijugum Clarke	Apiaceae	-	+
Sonchus asper Hill	Asteraceae	+	
Taraxacum officinale Weber	Asteraceae	+	-
Themeda anathera Hack.	Poaceae	-	+
Tragopogon kashmirianus Singh	Asteraceae	+	-
Trifolium pratense L.	Fabaceae	+	-
Verbascum thapsus L.	Scrophulariaceae	+	-
Veronica persica Poir	Scrophulariaceae	+	-
Vicia sativa L.	Fabaceae	+	-

+ = present; - = absent

Table 2. Distribution of plant species in various functional groups in the low elevation (LEG) and high elevation (HEG) grasslands.

Month	Functional groups							
	Graminoids		Legumes		Non-leguminous forbs		Total	
	LEG	HEG	LEG	HEG	LEG	HEG	LEG	HEG
April 2003	5	1	4	1	13	2	22	4
May	6	1	5	2	15	2	26	5
June	6	1	4	3	11	2	21	6
July	1	1	2	2	4	3	7	6
August	3	1	2	4	10	5	15	10
September	2	1	3	3	5	3	10	7
October	2	1	3	2	3	4	8	7
November	1	1	2	.	3	1	6	2
December	1	1	1	.	2	2	4	3
January	1	1	1	.	1	.	3	1
February	1	1	1	.	2	.	4	1
March 2004	2	1	3	1	3	1	8	3

Aboveground liv

and a high elevation (HEG) grassland during April 2003 to March 2004.

Months April May June July August

system of the low and high elevation grasslands (Table 3) revealed significant variation not only between the grasslands but also across different months and seasons. Biomass dynamics in different compartments of the producer sub-system is given below.

Aboveground live biomass

In the low elevation grassland, an upward trend in aboveground live biomass was observed from April to August, followed by gradual decrease up to March. More or less similar trend was observed in the standing crop of live aboveground biomass in the high elevation grassland (Table 3). The peak value of 422.0 g m^{-2} was recorded during August in the low elevation grassland while as in the high elevation grassland the peak value of 2189.3 g m^{-2} was also recorded in the same month. The lowest values were 26.6 g m^{-2} for low elevation grassland recorded during December and 18.7 g m^{-2} for high elevation grassland recorded during February.

Standing dead biomass

In respect of this compartment of producer sub-system, a fluctuating trend was observed in the low elevation grassland but in the high elevation grassland a downward trend from April to July was followed by a secular increase up to December (Table 3). The highest value of standing dead phytomass in the low elevation grassland was 558.6 g m^{-2} recorded during January while in the high elevation grassland a peak value of 2377.2 g m^{-2} was obtained in November. The lowest values were 83.0 g m^{-2} in low elevation grassland and 500.0 g m^{-2} in high elevation grassland during the months of June and July, respectively.

Litter biomass

In the low elevation grassland, the litter accumulation exhibited an upward trend from April to June followed by a fluctuating pattern (Table 3). On the contrary, in the high elevation grassland an upward trend from April to July was followed by a decline up to December. The litter mass in the low elevation grassland ranged from a low of 156.0 g m^{-2} to a high of 1111 g m^{-2} whereas in the high elevation grassland the corresponding values were 840 g m^{-2} and 1590 g m^{-2}, respectively.

Belowground biomass

The belowground biomass in the low elevation grassland showed a trend akin to that of litter but in the high elevation grassland no uniform trend was discernible (Table 3). In the low elevation grassland the belowground biomass during the study period ranged from 435 g m^{-2} to 1691.5 g m^{-2} while as in the high elevation grassland the biomass in this compartment varied from 358.3 g m^{-2} to 5016.5 g m^{-2}.

The ratio of belowground to aboveground live biomass (Table 4) is indicative of a more or less similar pattern in both low elevation grassland and high elevation grassland. The values remained around 1- 5 from May to October but beyond October an upward trend is noticeable with peak values of 63.49 observed during December in low elevation grassland and 126.24 during February in high elevation grassland.

Table 4. Ratio of below-ground to above-ground live biomass in the two grasslands (LEG ad HEG) during the study period

Month	LEG	HEG
April	7.90	9.07
May	1.70	3.14
June	2.57	2.25
July	1.87	2.30
August	1.56	0.65
September	2.05	2.92
October	5.08	5.97
November	19.62	62.12
December	63.49	20.83
January	28.00	57.08
February	26.40	126.24
March	30.42	30.71

Net Primary Productivity

The data on aboveground net primary productivity (ANP), belowground net primary productivity (BNP) and total net primary productivity (TNP) of the low elevation and high elevation grasslands are presented in Table 5. In the low elevation grassland, the ANP, BNP and TNP values were 1467.76 g m^{-2} y^{-1}, 1940.00 g m^{-2} y^{-1}, and 3408.21 g m^{-2} y^{-1}, respectively. In case of high elevation grassland the corresponding values were 3088.69, 6070.50 and 9161.19 g m^{-2} y^{-1}. In the low elevation grassland the highest ANP (654 g m^{-2}, 44.56%) was recorded during the month of May, while in high elevation grassland it was recorded during August (1308.80 g m^{-2}; 42.37%). In respect of BNP, highest value of 933.25 g m^{-2} (48.11%) was recorded during the month of December in the low elevation grassland while in high elevation grassland the highest BNP of 3581.50 g m^{-2} (58.98%) was observed during the month of September. For TNP, the highest values were 933.25 g m^{-2} (27.38%) for low elevation grassland during the month of December and for high elevation grassland it was 3581.50 g m^{-2} (39.09%) during the month of September (Table 5).

System Transfer Functions

The transfer function values are presented in Table 6. The data reveal a transfer of 43% and 34% of TNP to ANP in the low elevation grassland and high elevation grassland, respectively. 56% and 66% of TNP is transferred to BNP in the two grasslands. The percentage of ANP transferred to standing dead amounted to 41% in the low elevation grassland and 74% in high elevation grassland. Furthermore the data indicate that 100% transfer of standing dead phytomass to the litter compartment in high elevation grassland, but in low elevation grassland it was only 40%. Litter decomposition was 87% in low elevation grassland and 72% in high elevation grassland. In both types of grasslands, the BNP disappeared completely during the study period but only 95% and 83% of TNP disappeared in low and high elevation grasslands, respectively. The annual balance sheet of the dry matter of the studied grasslands in given in Table 7.

Table 6. System transfer function in different compartments of the two grasslands

Compartment	LEG	HEG
TNP to ANP	0.43	0.34
TNP to BNP	0.56	0.66
ANP to SD	0.41	0.74
SD to L	0.40	1.00
L to LD	0.87	0.72
BNP to RD	1.00	1.00
TNP to TD	0.95	0.83

Turnover Rates

In the LEG, the turnover rates of aboveground live biomass and belowground biomass were 3.48 and 1.58, respectively, whereas in the HEG the rates were 1.41 and 1.21 respectively.

Net Accumulation and Disappearance Rates

The rates of accumulation and disappearance of plant biomass in different compartments are presented in Figures 1 and 2. In the LEG, the rate of total net primary production was 9.31 g m^{-2} day^{-1} whereas the

Table 5. Above-ground (ANP), below-ground (BNP) and total productivity (TNP) in a low elevation (LEG) and high elevation (HEG) grasslands during different months.

Month	ANP		BNP		TNP	
	LEG	HEG	LEG	HEG	LEG	HEG
April	17.00	244.93	-	-	17.00	244.93
May	654.00	390.25	83.75	-	737.75	390.25
June	74.00	702.75	456.25	349.50	530.25	1052.25
July	97.00	368.00	-	324.75	97.00	692.75
August	102.00	1308.80	-	-	102.00	1308.80
September	-	-	-	3581.50	-	3581.50
October	-	-	-	-	-	-
November	-	-	250.00	1083.50	250.00	1083.50
December	-	31.32	933.25	-	933.25	31.32
January	513.36	-	-	658.25	513.36	658.25
February	10.40	-	216.75	75.00	227.15	75.00
March	-	42.64	-	-	-	42.64
Total	1467.76	3088.69	1940.00	6072.50	3408.21	9161.19

rates for ANP and BNP were 4.0 and 5.3 g m^{-2} day^{-1}, respectively. In the HEG, the rates for TNP, ANP and BNP were 25.03, 8.44 and 16.59 g m^{-2} day^{-1}, respectively. The accumulation rate in the standing dead and litter compartments of low elevation grassland was 1.65 and 4.08 g m^{-2} day^{-1}, respectively; the same for the high elevation grassland was 6.3 g m^{-2} day^{-1} in both the compartments. The rates of disappearance of litter and belowground biomass were 3.56 and 5.30 g m^{-2} day^{-1} respectively in the LEG, and 4.51 and 16.59 g m^{-2} day^{-1} respectively in the HEG. The total disappearance rates for the two grasslands were 8.86 g m^{-2} day^{-1} (LEG) and 21.10 g m^{-2} day^{-1} (HEG).

DISCUSSION

To the extent that driving factors of NPP, such as climate, disturbance, soil, and herbivory vary across landscapes due to variation in topography, climate, and soil, we expected biomass and NPP to vary in the two grasslands investigated during the present study. In line with this hypothesis aboveground live plant biomass was more in high elevation grassland than low elevation grassland (Table 3) and in both the grasslands aboveground live biomass reflected a seasonal pattern with maximum accumulation in August presumably due

Table 7. Annual balance sheet of dry matter (g m^{-2}) of a low elevation (LEG) and a high elevation (HEG) grassland

Attribute	LEG	HEG
A. Above-ground net primary production		
Initial biomass	55.00	174.50
Above-ground net production	1467.76	3088.69
Total input into the system	1522.76	3263.19
Transfer to standing dead	604.64	2293.36
Biomass at the end	38.00	61.32
Total output	642.64	2354.68
Unaccounted for	880.12	908.51
B. Below-ground net primary production		
Initial biomass	435.00	1582.50
Below-ground net production	1940.00	6072.50
Total input into the system	2375.00	7654.50
Disappearance of below-ground biomass	1940.05	6071.75
Below-ground biomass at the end	1156.25	1883.25
Total output	3096.25	7955.00
Unaccounted for	721.25	300.50
C. Standing dead		
Initial amount of standing dead	112.00	947.75
Production of standing dead	604.64	2293.36
Total input into the system	716.64	3241.11
Transfer of litter	421.64	2293.36
Standing dead biomass at the end	295.00	1032.00
Total output	716.64	3325.36
Unaccounted for	--	84.25
D. Litter		
Initial amount of litter	156.00	872.50
Litter production	1492.20	1698.70
Total input into the system	1648.20	2571.20
Litter disappearance	1302.20	1651.20
Litter biomass at the end	345.00	920.00
Total output	1647.20	2571.20
Unaccounted for	1.00	--

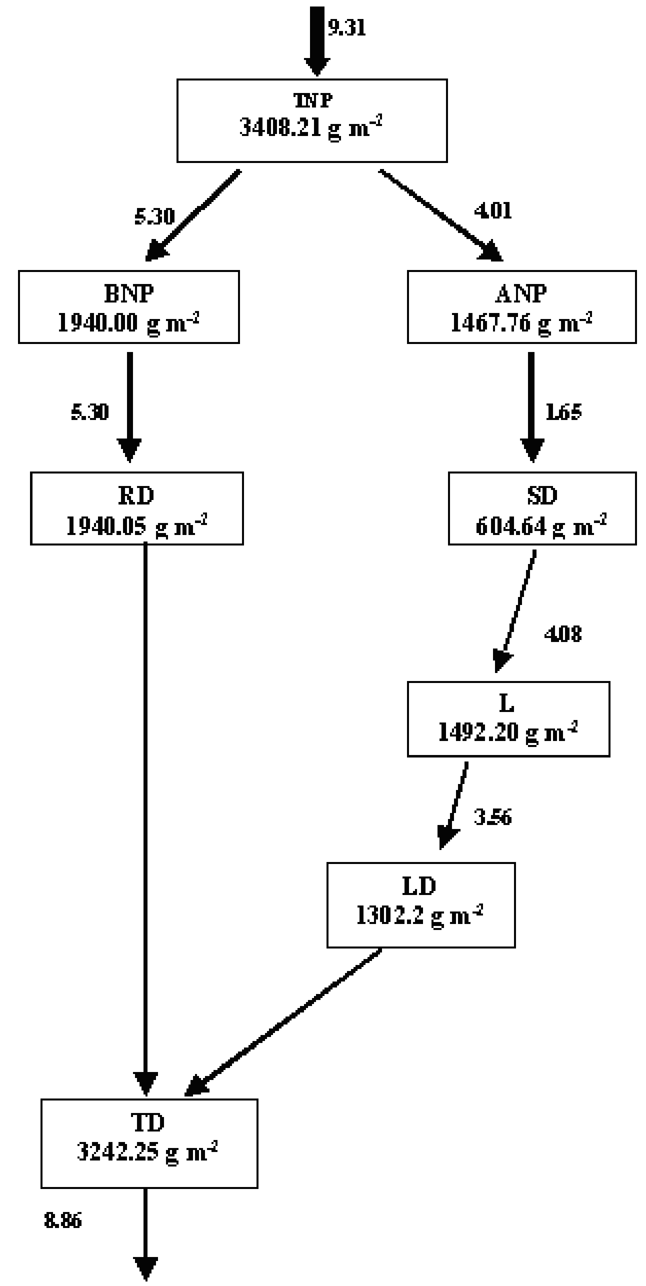

Figure 1. Net primary productivity, accumulation and disappearance rates during the study period (366 days) in a low elevation grassland.

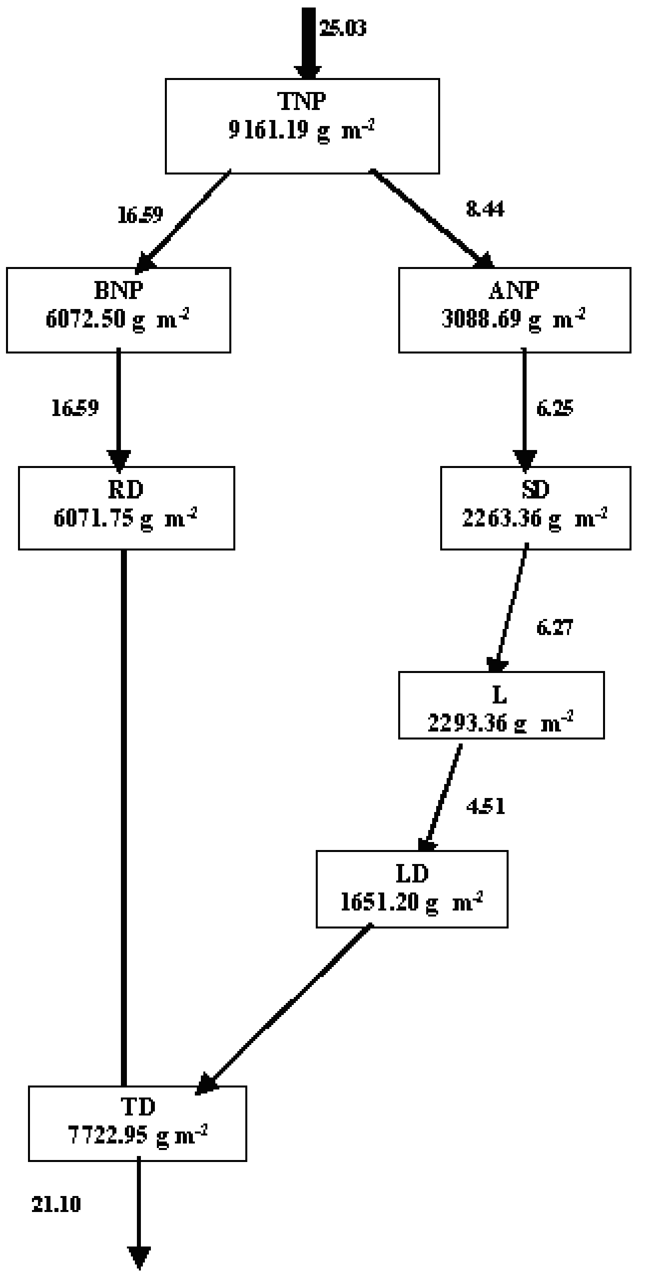

Figure 2. Net primary productivity, accumulation and disappearance rates during the study period (366 days) in a high elevation grassland

to prevalence of favourable climatic conditions during this part of the year. Winter, being the most unfavourable season, had a depressing effect on aboveground live plant biomass accumulation. Similar seasonal pattern has been also reported by Singh and Ambasht (1975), Singh and Joshi (1979) and Karunaichamy and Paliwal (1994) in tropical grasslands of India, where minimum biomass accumulation also occurs during winter but higher biomass production is recorded after June and October rains. Unlike tropical grasslands of India, the grasslands investigated during the present study showed higher belowground plant biomass compared to live aboveground plant biomass throughout the study period and such a trend according to Bazilevich and Titlyanova (1980) and Rice et al. (1998) is characteristic of temperate grasslands. This observation also draws support from similar findings of Sims and Singh (1978) recorded in North American grasslands who implicated low temperature and xeric conditions for this pattern. Such factors, could be also responsible for higher belowground biomass in high elevation grassland (Table 3). However, the relationship between dynamics of belowground biomass and abiotic variables are not easily amenable to interpretation because of involvement of a multitude of factors, like soil water, soil and air temperature (Lauenroth and Whitman 1977) and disappearance of old roots (Rice et al. 1998). Standing dead plant biomass and litter were also higher in high elevation grassland. During the study period the dry mass in these two compartments showed variable pattern which is attributable to different phenologies, maturation, and senescence patterns of plant species comprising the producer sub-system of the grasslands (Bazilevich and Titlyanova 1980). Climatic variables, like temperature (Seastedt et al. 1998) and precipitation (Sims et al. 1978) are also known to affect seasonal dynamics of standing dead and litter biomass.

Aboveground net primary productivity (ANP) was relatively lower (1,467.76 g m^{-2}) in the low-elevation grassland in comparison to 3,088.69 g m^{-2} of ANP in high-elevation grassland (Table 5). In contrast to usual production values of 40 g m^{-2} to 500 g m^{-2} recorded in comparable high-elevation Himalayan grasslands (Sundriyal 1995), the present values are significantly higher. Peak ANP of 654 g m^{-2} (44.56% of total annual ANP), in the low-elevation grassland, was recorded during May, while as peak value of 1,308.80 g m^{-2} (42.37% of the total annual ANP) in the high-elevation grassland was recorded during August (Table 5). This variation in the peak ANP of the two grasslands could be ascribed to elevation; a complex factor which co-varies with other environmental variables as well and which collectively influence annual ANP (Sundriyal, 1992). Less than half (43%) of TNP was transferred to aboveground sub-system in the low-elevation grassland while as only 34% was transferred to aboveground compartment in the high-elevation grassland. Shorter growing season and harsh environmental conditions at higher altitudes are the likely factors that favour higher resource allocation to the belowground sub-system (Table 5).

In comparison with most of the low and mid elevation central Himalayan grasslands, belowground primary productivity of the two Kashmir Himalayan grasslands was strikingly higher. Such differences can be explained on the basis of differences in multitude of factors, like precipitation, potential evapotranspiration, solar radiation, temperature (French 1971, Singh and Yadava 1974, Risser et al. 1981, Singh and Krishnamurthy 1981), soil nutrients (Owensby et al. 1970, Risser et al. 1981), floristic composition (Gupta and Singh 1982), temporal shift in dominance of C_3 and C_4 species (Knapp et al. 1998), level of disturbance and successional status (French 1971), that either singly or in various combinations, control primary productivity in these grasslands.

The annual balance sheets of dry matter presented in Table 7, reveals that the total input into above-ground, belowground, standing dead and litter compartments is not usually balanced by total output and, in fact, some portion of the dry matter remained unaccounted for. Such results are in conformity with those obtained by Golley (1965), Struik (1965), Mitchell (1973) and Karunaichamy and Paliwal (1994). The net accumulation and disappearance of dry matter (Figures 1 and 2) and system transfer functions of two grass-lands make it apparent that unlike most Indian grass-lands, the present grasslands transfer only 43.06% and 33.71% of TNP to ANP at rates of 4.01 g m^{-2} day^{-1} and 8.44 g m^{-2} day^{-1}, respectively in low and high elevation grasslands. On the contrary, 56.92% and 66.63% of TNP was transferred to BNP at rates of 5.30 m^{-2} day^{-1} and 16.59 m^{-2} day^{-1}. Similar observations of higher allocation to BNP have been made by Sims and Singh (1971) in North American grasslands who attributed it to low mean temperatures. The turnover rates of above-ground live biomass and belowground biomass in the LEG were 3.48 and 1.58, respectively and the corres-ponding values in the HEG were 1.41. and 1.21. Shorter growing season and colder environment at higher altitudes are likely factors that favour higher resource allocation to the below-ground sub-system.

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Table 3. Monthly variation in the standing crop of biomass (g m^{-2}) in different compartments of the producer sub-system of a low elevation (LEG) and a high elevation (HEG) grassland during April 2003 to March 2004.

Months	Above-ground live plant biomass		Standing dead plant biomass		Litter		Below ground biomass	
	LEG	HEG	LEG	HEG	LEG	HEG	LEG	HEG
April	55.0 ± 13.6	174.5 ± 58.25	112.0 ± 21.8	947.8 ± 153.0	156.0 ± 39.5	872.5 ± 79.5	435.0 ± 98.0	1582.5 ± 341.0
May	304.0 ± 82.0	458.3 ± 132.5	100.0 ± 14.4	865.0 ± 98.5	343.0 ± 49.9	979.0 ± 121.0	518.8 ± 120.0	1438.3 ± 201.5
June	378.0 ± 62.0	794.5 ± 243.0	83.0 ± 13.2	683.5 ± 129.5	784.0 ± 68.2	1345.5 ± 233.5	975.0 ± 146.3	1787.8 ± 412.0
July	404.0 ± 177.2	918.0 ± 31.12	154.0 ± 16.8	500.0 ± 11.3	221.0 ± 104.0	1590.0 ± 280.0	756.3 ±146.3	2112.5 ± 406.5
August	422.0 ± 105.0	2189.3 ± 437.5	137.0 ± 45.0	537.5 ± 79.5	1111.0 ± 273.8	1255.0 ± 53.0	662.5 ± 277.3	1435.0 ± 147.5
September	296.0 ± 123.0	1717.2 ± 269.7	214.0 ± 40.3	584.0 ± 140.3	356.0 ± 54.0	1173.2 ± 155.7	608.3 ± 300.3	5016.5 ± 330.0
October	100.0 ± 24.96	304.0 ± 48.5	253.2 ± 43.9	914.6 ± 149.2	521.2 ± 90.0	840.0 ± 159.6	508.3 ± 170.0	1816.5 ± 202.0
November	38.6 ± 12.2	46.7 ± 6.12	438.6 ± 90.2	3546.7 ± 204.4	360.0 ± 18.3	1537.2 ± 119.8	758.3 ± 14.5	2900.0 ± 126.0
December	26.6 ± 15.1	78.0 ± 25.4	326.6 ± 90.4	2377.2 ± 402.8	688.0 ± 149.3	753.3 ± 125.4	1691.5 ± 52.0	1625.0 ± 229.0
January	36.0 ± 22.3	40.0 ± 10.6	558.6 ± 55.5	1564.0 ± 83.5	960.0 ± 133.8	962.7 ± 243.5	1008.3 ± 289.8	2283.3 ± 242.8
February	46.4 ± 3.6	18.7 ± 2.2	540.0 ± 93.8	1810.7± 174.2	1008.3 ± 289.8	1037.3 ± 98.3	1225.0 ± 151.3	358.3 ± 521.0
March	38.0 ± 4.0	61.3 ± 2.3	295.0 ± 136.6	1032 ± 40.6	345.0 ± 72.04	920.0 ± 34.16	1156.3 ± 129.8	1883.3 ± 496.5