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Species richness, productivity and quality assessment of grassland resources in hill agroecosystem of western Himalaya

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ABSTRACT

Livestock contribution in agricultural economy is significantly higher in hilly regions of India. A detailed study was carried out to assess the productivity, species richness and diversity of grasses of the grasslands in different hill agro-ecosystems of Kangra district of Himachal Pradesh in western Himalaya. *Saccharum spontaneum* (low hills), *Chrysopogon echinulatus* (mid hills) and *Festuca* spp. (high hills) were observed as the most dominant species in hill agro-ecosystems. Productivity assessment was done at five locations, viz. open forest area; enclosed forest area; community land; farmers' field; and wasteland in each hill zone. High species richness and diversity was observed in mid hill zone as compared to low and high hills. The mean production level was recorded highest in low hills closely followed by mid hills; much less in high hills. Amongst the land-use systems, highest biomass production was recorded at farmers' field followed by community land and least in wasteland situation. The average herbage production obtained through six cuts at periodic intervals (March to December) was 3,202 DM kg/ha, while in single harvest it was 2,249 DM kg/ha (low-hill conditions); 2,893 and 1,924 DM kg/ha (mid-hill conditions) and 1,399 and 850 DM kg/ha (high-hill conditions), respectively. Averaged over the different locations, 6.01, 6.64 and 10.87% crude protein (CP) was observed (in multicut situation) in low, mid and high hills respectively. Average herbage production obtained through six cuts at periodical intervals (March-December) was consistently higher as compared to single harvest in all the three zones.

Key words: Biomass potential, Diversity indices, Forage quality, Grassland resource, Soil properties

Himalaya is recognized for its ecosystem services in the form of regulating slope stability and hydrology, sustaining high levels of biodiversity and human wellbeing and is considered as one of the richest biodiversity hot spot in the world (Dar *et al.* 2016). Livestock rearing is one of the most important components of rural economy in western part of Himalaya and pastures are the main forage resource base in the Himalayan agriculture (Dev *et al.* 2001, Tewari *et al.* 2012). Grasslands support the livestock sector as well as important soil and water conservation functions, and offer biologically diverse resources in this region (Singh *et al.* 2008). However, productivity of grasslands in western Himalayan states of India, particularly Himachal Pradesh is far below the potential (Dev *et al.* 2006). Furthermore, in spite of abundant grassland (1.2 million ha) and other feed resources, total available biomass for livestock feeding is insufficient (shortage of about 26 and 54% of green and dry fodder, respectively) in Himachal Pradesh (Dev *et al.* 2001, 2006). Lack of management interventions, heavy and indiscriminate grazing and weed infestation are the major constraints for productive grasslands (Pathania and Dev 2011). Precipitation, altitudinal variation, livestock grazing, livestock intensity and grazing systems have also affected the diversity and richness of the pasture species (Panitsa *et al.* 2010, Gaujour *et al.* 2012).

Overgrazing coupled with poor management practices have led to the deterioration of grasslands in terms of species richness, quality and productivity to such an extent that needs rehabilitation (Kemp *et al.* 2013). Keeping above facts in view, the study was carried out with the aim to assess the

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biomass potential (through multicut and single cut) and species richness, diversity of grassland resources of Kangra district of Himachal Pradesh state, India in western Himalaya.

MATERIALS AND METHODS

Study site and location map: The western Himalayan region covers three states of India, viz. Himachal Pradesh, Uttarakhand (eastern side) and Jammu and Kashmir (western side). The sample sites of the study were in three zones, viz. low hill (sub-tropical zone); mid hills (sub humid zones); and high hills (temperate wet zones). The study was carried out for three years (from 2010 to 2012) in Kangra district of Himachal Pradesh state in India. Three blocks in Kangra district, viz. Nurpur, Bhavarna, and Baijnath were selected for studying the biomass potential (under multicut and single cut situation) and assessing the grass species richness and diversity. The climate of the study area varied from hot summer to severe cold winter. The summer temperature may go upto 40°C (low hills), 30°C (mid hills) and 20°C (high hills), while minimum temperature may go down upto 10°C, freezing level and –5°C in all the three zones, respectively (Singh *et al.* 2009).

Field survey and ground truthing: The survey routes were planned to cover each landuse system in all the categorized hill zones, viz. high (>1500 m), medium (750 m–1500 m) and low (< 750 m) altitudes. Sampling of the pasture species was done randomly using transect plot method (Robins *et al.* 2001, Sabetpour *et al.* 2002, Jouri 2010) in each landuse system (Body and Svejcar 2004) and the plot size was determined by minimal area method. Sample biomass were collected from 1 m × 1 m size plots each for single harvest and multi-cuts, which were laid within a 10 m × 10 m stretch of homogenous vegetation area following nested sampling approach (minimal area method, Cain 1932) (Picard *et al.* 2012, Deb *et al.* 2016).

Soil analysis: Soil samples were collected from each landuse with the help of soil augur from 0–30 cm soil depth. Each representative soil sample consisted of collection and composition of 10 soil samples randomly taken from same landuse. Soil samples were analyzed for available N (ammonical nitrogen), which was measured by the method as suggested by Subbiah and Asija (1956); available P (Olsen *et al.* 1954), 1N ammonium acetate exchangeable K (Hanway and Heidel 1952) and organic C (Walkley and Black 1934). The pH of soil was estimated using pH meter (1:2.5 soil and water ratio). Reference for pH is Combined glass-colomel electrode (Jackson 1973) of aqueous suspensions (1:2.5 soil/solution ratio). Soil samples were air dried, ground in a wooden pestle and mortar, passed through 2 mm stainless sieve before going for analysis. Before analysis, the samples were stored for about 15 days in polythene bags.

Harvesting of grassland herbage: In each block, five land use systems, viz. open forest area, enclosed forest area, community land, farmers' field (old fallow) and wasteland were selected to represent the available grazing resources.

Table 1. GPS location of sampling at different locations

	Latitude (N)	Longitude (E)	Altitude (amsl)
Low hills			
Open forest	32° 18' 32.68"	75° 52' 34.48"	565
Enclosed forest	32° 18' 34.19"	75° 52' 34.81"	578
Community land	32° 18' 31.30"	75° 52' 33.38"	554
Farmer's field (Fallow land)	32° 18' 31.69"	75° 52' 31.60"	565
Wasteland	32° 18' 32.61"	75° 52' 31.03"	577
Mid hills			
Open forest	32° 05' 15.26"	76° 31' 58.46"	1162
Enclosed forest	32° 05' 19.96"	76° 32' 02.42"	1176
Community land	32° 05' 17.78"	76° 32' 10.42"	1180
Farmer's field (Fallow land)	32° 05' 24.42"	76° 31' 57.88"	1178
Wasteland	32° 05' 14.16"	76° 31' 55.53"	1161
High hills			
Open forest	32° 02' 28.68"	76° 43' 45.83"	1577
Enclosed forest	32° 02' 32.42"	76° 43' 43.40"	1591
Community land	32° 02' 30.94"	76° 43' 37.81"	1546
Farmer's field (Fallow land)	32° 02' 34.94"	76° 43' 34.88"	1545
Wasteland	32° 02' 31.04"	76° 43' 41.71"	1571

The details of the observational sites are presented in Table 1 and location map of the study sites is given in Fig. 1. The scale of 1/250000 was developed for determining landform units for location map and the territory of study area.

Harvesting of the herbage was done from each land use site, which serves as non over lapping sub populations or strata comprising the entire population and then collecting five samples (1m × 1m) from each land use site through simple random sampling. The plots were permanently marked and harvesting of the herbage was done in the same plot during different months and over the years as per harvest schedule. Each sample area was marked and same area were harvested over the years for biomass estimation. Area which was not in the sample area was not grazed, however was harvested (no observations recorded). Harvesting of herbage was done in mid of March, June, July, August, September and December and single harvest was done in September (as per farmers' practice) every year. The plant samples were stored in tassel bags and dried in an oven at 60ºC and then ground in stainless steel grinder. The samples were stored for about 12 days before analysis. Proximate composition analysis was done as per Association of Official Analytical Chemists (AOAC 1980). The proximate composition was done for evaluating the quality of forage. The values obtained for proximate composition (repeated cuts and single harvest over the years) were pooled and then averaged. The data collected were subjected to statistical analysis for measuring various phenomena by using analysis of variance and chi square test.

Relative density and diversity indices for grass species: The relative density was calculated as:

$$\text{Relative density} = \frac{\text{Number of individual of ith species}}{\text{Number of individual of all the species}} \times 100$$

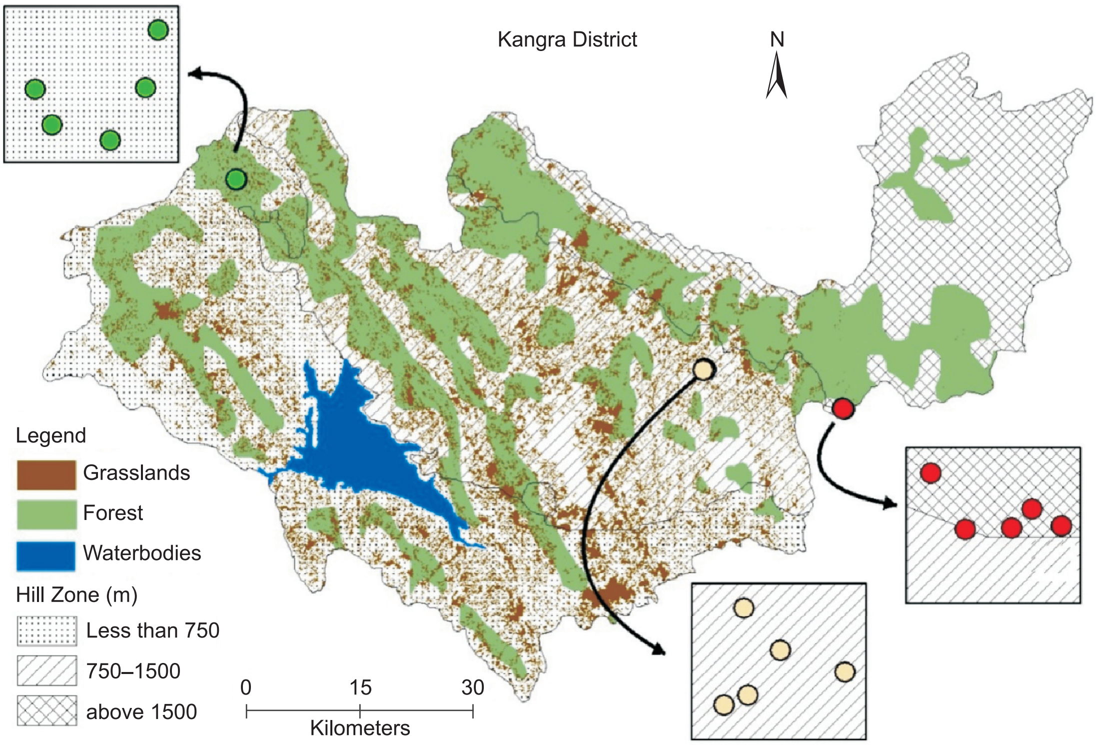

Fig. 1. Location map of the study area.

Diversity in grasses refers to the number of species and their relative abundance in a defined area and it incorporate both richness and evenness of grass species (Saderson *et al.* 2004). Diversity and richness indices, viz. Shannon diversity index (Shannon and Weiner 1963), Simpson index (Simpson 1949), Menhinick's index (Whittaker 1977), Berger-Parker Dominance index (Berger and Parker 1970), Simpson index approximation (Simpson 1949), Margalef's richness index (Margalef 1958), Gini Coefficient and Routledge beta-R-Index (Routledge 1977) were calculated for diversity and richness analysis of different pasture composition in three hill zones (low, mid and high) of Kangra district. All the diversity indices have strong correlation, however differ in their theoretical interpretation and foundation and are not interchangeable.

RESULTS AND DISCUSSION

Soil fertility status at different locations: Altitudinal variation in different location had affected the fertility status of the soil. Average pH at different locations was found in acidic range and the magnitude of acidity was less in low hills and high hills in comparison to mid hills. Average organic carbon content of soils was in medium range irrespective of altitudinal variations. Data in Table 2 showed that average available nutrients (N, P and K) content of soil was observed highest in high hills followed by mid hills and low hills. Amongst the locations, highest values

Table 2. Soil properties at different locations in three hill zones

Site/Location	pH	Organic C (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Low hills					
Open forest	6.52	0.68	192	56	89
Enclosed forest	6.78	0.97	203	58	97
Community land	6.42	0.59	184	54	90
Farmers' field	6.37	0.62	172	47	85
Wasteland	6.45	0.58	165	42	76
Mean	6.51	0.69	183	51	87
Mid hills					
Open forest	5.98	0.76	202	62	97
Enclosed forest	5.92	1.04	234	68	106
Community land	6.14	0.71	201	64	95
Farmers' field	6.18	0.69	208	58	82
Wasteland	6.20	0.65	195	52	78
Mean	6.08	0.77	208	61	92
High hills					
Open forest	6.27	0.72	225	68	101
Enclosed forest	6.18	1.08	245	72	111
Community land	6.31	0.73	232	64	104
Farmers' field	6.24	0.68	240	63	98
Wasteland	6.15	0.75	208	58	87
Mean	6.23	0.79	230	65	100

of these nutrients (N, P and K) were found in the soils of enclosed forest and lowest in soils of wasteland. Average value of available N and K in all the three locations was found in low range, whereas the status of available P was high irrespective of the altitudinal variations.

Grasslands and vegetation: In Kangra district, grasslands were found 18, 20 and 4% of total area of low-, mid- and high-hills, respectively. About 15% (84,221 ha) land area was covered under grasslands and about 33% area was under forests. Grassland area was recorded high in mid hill zone (20%), while maximum forest cover of 41% was recorded in high hill zone (Table 3). The three hill zones supported diverse vegetation.

Table 3. Grassland and forest resources in Kangra district of Himachal Pradesh (India)

Hill zones	Geographical area (ha)	Grasslands		Forest	
		Area (ha)	(%)	Area (ha)	(%)
Low hill (<750 m)	208816	37788	18	49879	24
Mid-hill (750 m–1500 m)	198237	40198	20	73441	37
High hill (> 1500 m)	156779	6236	4	64376	41
Total	563832	84222	15	187696	33

Relative density of different pasture species in grassland of the three hill zones: On vegetation transects, 10, 13 and 11 pasture species were found in low, mid and high hills, respectively (Table 4). The major pasture species belongs to poaceae family, while few were to fabaceae. It was observed that in zone-I (low-hills), first two dominant grasses were less palatable as compared to *Chrysopogon gryllus* (13%) and *Bothriochloa pertusa* (11%), while *Themeda anathera* (4%) was the lowest species in composition observed. Legume component in this zone was by and large negligible. In zone-II (mid hills), relative composition of palatable grasses were higher as compared to Zone-I. *Trifolium pratense* and *Lotus corniculatus,* represented the fabaceae family although in very less relative density. Relative density of palatable grasses were observed higher in Zone-III as compared to other hill zones. It was observed that in relative density of pasture species, number of legume species increased with increasing altitude.

Diversity indices for three hill zones of western Himalaya: When we observed the pasture land, it's first appearance was uniform surface with homogenous mixture of grasses. However, based upon diversity indices, mid hills

Table 4. Relative density of different pasture species in three hill zones

Species	Family	Relative density (%)			Annual (A)/ Perennial (P)	Photosynthesis pathway (C3/C4)	Palatability (Low/Medium/ High)
		Zone-I (Low hills)	Zone-II (Mid hills)	Zone-III (High hills)			
Grasses							
Agropyron spp.	Poaceae	7	-	8	P	C3	LP
Agrostis stolonifera	Poaceae	-	13	10	A	C3	MP
Alopecurus myosuroides	Poaceae	-	8	5	A	C3	LP
Arundinella nepalensis	Poaceae	-	-	-	P	C4	LP
Bothriochloa pertusa	Poaceae	11	-	-	P	C4	P
Chrysopogon echinulatus	Poaceae	-	24	-	P	C4	P
Chrysopogon gryllus	Poaceae	13	-	-	P	C4	P
Cynodon dactylon	Poaceae	6	-	-	P	C3	MP
Dactylis glomerata	Poaceae	-	5	15	P	C3	HP
Dichanthium annulatum	Poaceae	7	4	-	P	C4	P
Eragrostis spp.	Poaceae	8	4	-	A	C4	P
Festuca spp.	Poaceae	-	2	18	P	C3	HP
Heteropogon contortus	Poaceae	9	9	-	P	C4	P
Imperata cylindrica	Poaceae	15	11	-	P	C4	LP
Pennisetum flaccidum	Poaceae	-	-	12	P	C4	LP
Pennisetum orientale	Poaceae	-	9	-	P	C4	MP
Phleum alpinum	Poaceae	-	-	6	P	C3	P
Poa alpina	Poaceae	-	-	7	P	C3	P
Poa pratense	Poaceae	-	3	-	P	C3	P
Saccharum spontaneum	Poaceae	16	-	-	P	C4	LP
Themeda anathera	Poaceae	4	-		P	C4	LP
Legumes							
Lotus corniculatus	Fabaceae	-	1	8	P	C3	P
Trifolium pratense	Fabaceae	-	2	2	P	C3	HP
Trifolium repens	Fabaceae	-	-	3	P	C3	HP
Other grasses and legumes	-	4	5	6	A/P	-	-

LP, Less palatable; MP, medium palatable; P, palatable; HP, highly palatable.

(Zone-II) was observed with higher diversity and richness of pasture species followed by high hills and low hills. Shannon diversity for pasture community was observed slightly higher in zone-II (2.351) closely followed by zone-III (2.339) and zone-I (2.303) (Table 5). Simpson's index was observed higher (0.110) in mid hills (zone-II) as compared to low hills and high hills (0.099). Simpson index approximation was also observed higher in mid hills (0.119) as compared to low and high hills (0.108). Presence of higher no. of grass species in total community in mid hills resulted into higher values of diversity indices than in low and mid hills. Zone-II observed with highest richness of species (1.400-Menhinick index; 2.823-Margalef richness index) followed by zone-III and zone-I. As per Berger-Parker dominance index, the proportion of common grasses were higher in mid hills (0.240) followed by high hills (0.180) and least in low hills (0.160). Similar trends were observed in case of Gini coefficient. The mid hills were observed with high beta-R index (4.446) followed by high hills (4.667) and least in low hills (3.667). In biplot (Fig. 2) indices, viz. Simpson Index, Menhinik Index, Simpson Index Approximation, Berger-Parker Dominance Index and

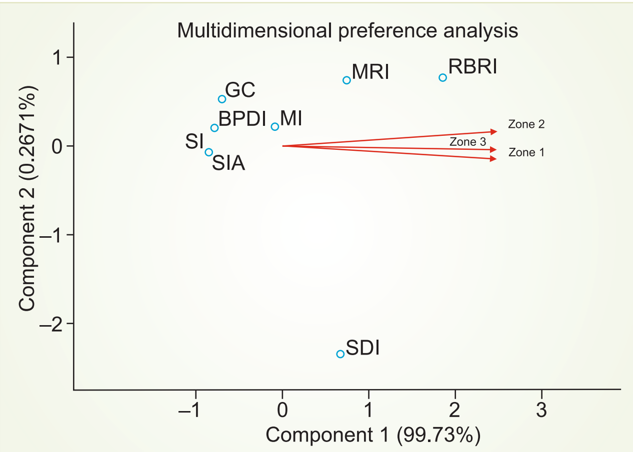

Fig. 2. Multidimensional preference analysis of diversity indices.

Table 5. Diversity indices for pasture composition in low, mid and high hills

Indices	Zone-I (Low hills)	Zone-II (Mid hills)	Zone-III (High hills)	Average
Shannon diversity index	2.303	2.351	2.339	2.331
Simpson index	0.099	0.110	0.099	0.103
Menhinick Index	1.100	1.400	1.200	1.233
Simpson index approximation	0.108	0.119	0.108	0.112
Berger-Parker Dominance index	0.160	0.240	0.180	0.193
Margalef richness index	2.171	2.823	2.389	2.461
Gini Coefficient	0.246	0.414	0.300	0.320
Routledge beta-R-Index	3.667	4.667	4.000	4.111

Gini Coefficient are in clusters indicating having more common features as compared to Shannon Diversity Index, Margalef Richness Index and Routledge beta-R-Index. Several vector points towards the right side of the plot, toward a region with no indices. This is the region between the indices, where Shannon Diversity Index, Margalef Richness Index and Routledge beta-R-Index indicating their dominance in all three zones.

Biomass potential: Pooled data of average biomass potential of different hill zones under single and multicut situation is presented in Table 6. Irrespective of all the three hill zones, multicut produced higher biomass than single cut across all the land use as evident from Fig. 3. Average herbage production (dry matter) obtained through six cuts at periodic intervals (March to December) in low hills conditions was observed as 10 and 129% higher than the average herbage production in multicut situation in mid and high hills, respectively. In single cut situation, average herbage production was 29.76 (low-hill conditions), 33.49 (mid-hill conditions) and 39.24% (high-hill conditions) lower than multi-cut in respective hill zones. Whereas, in single cut situation, average herbage production was about 72 and 226% higher in case of low hill as compared to mid and high hill situation. Biomass production of mulit-cut situation was observed to be about 42 (low hill), 50 (mid hill) and 64% (high hill) higher as compared to single harvest. Data also indicated that among different cuts in a year, the August month cut at farmers' fields and at community land recorded highest biomass production in all the three zones. It is visually evident from the plots (Figs 4 and 5) that difference in altitudes has significant effect on biomass production, which is also confirmed from ANOVA, where different hill zones taken as independent factors were highly significant ($P<0.01$). In both cases of single cut and multicut, the biomass production in wastelands was the least in all hill zones. Biomass production in all locations was highest in the low hills followed by mid hill and high hills, respectively in both cases of multicut and single cut. With regards to biomass potential depending on different locations, herbage production was highest in farmers' field under multicut situation, followed by community land, enclosed forest, open

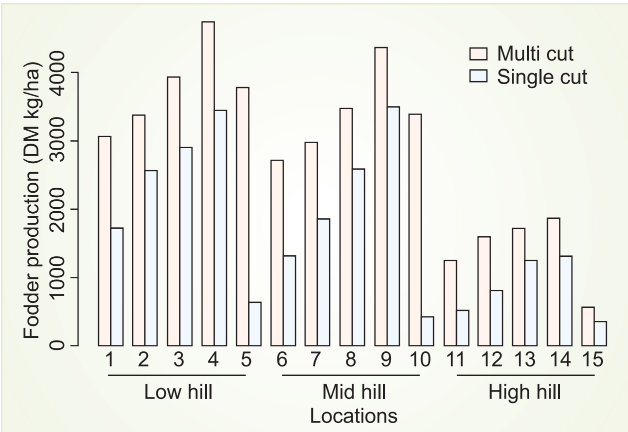

Fig. 3. Fodder production at different landuse systems under multi and single cut situations.

Table 6. Biomass potential and proximate composition of grasses at different locations

Site/Locations	Multicut					Single cut				
	Biomass yield (DM kg/ha)	CP (%)	Crude protein yield (kg/ha)	CF (%)	Total ash (%)	Biomass yield (DM kg/ha)	CP (%)	Crude protein yield (kg/ha)	CF (%)	Total ash (%)
Low hills										
Open forest	3057	4.91	150.1	40.14	4.62	1712	4.07	69.7	45.49	4.08
Enclosed forest	3367	6.01	202.4	32.52	6.26	2565	5.62	144.2	38.28	5.66
Community land	3925	6.82	267.7	31.17	5.95	2885	6.13	176.9	34.19	5.03
Farmers' field	4732	7.97	377.1	39.62	6.81	3445	6.57	226.3	42.75	5.92
Wasteland	928	4.35	40.4	43.42	6.09	636	4.01	25.5	47.21	5.48
Average	3202	6.01	192.4	37.37	5.95	2249	5.28	118.7	41.58	5.23
Mid hills										
Open forest	2705	6.02	162.8	40.07	4.15	1308	4.43	57.9	44.64	3.87
Enclosed forest	2985	5.84	174.3	36.24	7.91	1832	5.87	107.5	39.27	6.52
Community land	3481	7.96	277.1	41.71	8.02	2593	6.64	172.2	42.84	6.98
Farmers' field	4372	8.57	374.7	38.98	8.91	3468	7.23	250.7	41.83	7.23
Wasteland	921	4.80	44.2	36.41	7.80	420	4.06	17.1	39.17	6.88
Average	2893	6.64	192.1	38.68	7.36	1924	5.65	108.7	41.55	6.30
High hills										
Open forest	1248	9.41	117.4	33.64	10.25	516	7.53	38.9	38.48	8.94
Enclosed forest	1596	11.57	184.7	36.69	9.96	812	9.74	79.1	39.12	8.62
Community land	1716	13.03	223.6	34.16	11.01	1253	11.17	140.0	37.43	9.87
Farmers' field	1872	11.97	224.1	34.28	9.75	1313	9.08	119.2	38.09	8.54
Wasteland	563	8.37	47.1	36.60	9.47	357	6.91	24.7	34.08	8.71
Average	1399	10.87	152.1	35.07	10.09	850	8.89	75.6	37.44	8.94
Overall average	2498±312.51					1674±279.44				
C.D for land use system	2392.7					1512.4				

Multicut=Mid-March; Mid-June; Mid-July; Mid-August; Mid-September; Mid-December (Single harvest was done during September as per farmers' practice).

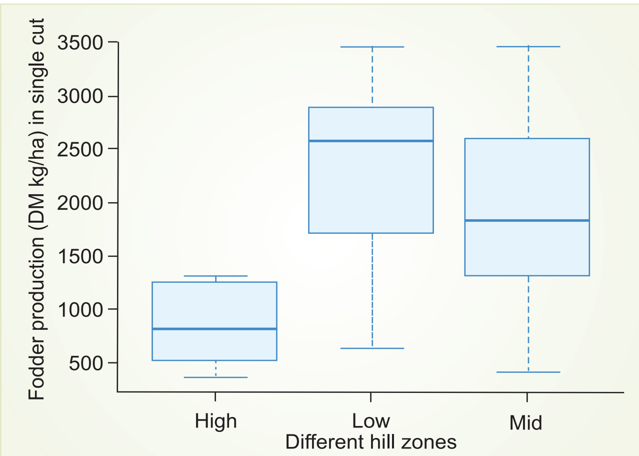

Fig. 4. Fodder production in different hills with single cut.

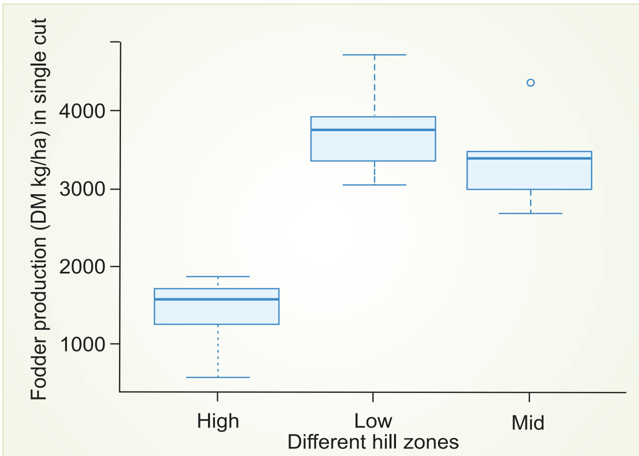

Fig. 5. Fodder production in different hills with multi cut.

forest and wastelands in low, mid and high hills, respectively. Likewise similar trend was observed in single cut situation, where also highest biomass production was recorded at farmers' field (Table 6). All the samples collected from three hill zones irrespective of locations, when several cuts were taken during different months are depicted in Fig. 6. The biomass production during mid of March, June and December were more or less same and less across different hill types as compared to mid of July, August and September. Biomass production attained its peak during the month of August and then again gradually decreased.

Proximate composition of herbage: By and large the

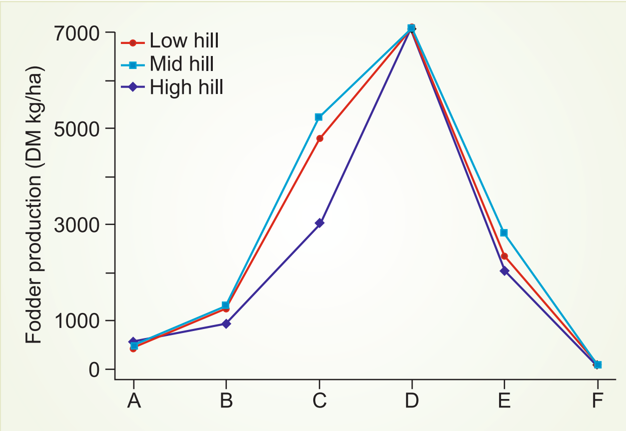

Fig. 6. Fodder production during different months at all locations.

average crude protein (CP) content of grasses at different locations was found highest in high hills followed by mid and low hills, respectively (Table 6). Single harvest (September cut) also showed similar trend as observed in multicuts, however CP values were observed substantially lower in single cut. Among different locations, average crude protein observed in the herbage obtained from farmers' field (multicut situation) was highest in high hills followed by mid hills and low hills. However, in single cut, highest crude protein content was observed in herbage obtained from community land in high hills and at farmers' field and in mid and low hills, respectively. Average crude protein yields remained almost same in low and mid hills, but higher than the high hills. Although high hills recorded average 51–56% lesser biomass yield in multicut as compared to low and mid hills, but crude protein yield was lesser only upto 20%. By and large similar trend was observed with single cut. Average crude fibre content was observed higher in low and mid hills as compared to high hills in single and multicut situation. Among different locations, highest crude fibre was observed in wasteland (43%-low hills), community land (42%-mid hills) and in enclosed forest (37%-high hills). Therefore, it can be concluded that there is no relation of crude fibre with sites in single and multicut situation. Total ash content in multicut situation varied in the average range of 4.62–6.81% (low hills); 4.15–8.91% (mid hills) and 9.47- 11.01% (high hills). In single harvest, ash content varied in the range of 4.08–5.66% (low hills), 3.87–7.23% (mid hills) and 8.54–9.87% (high hills).

Relatively lower value of pH in mid hills as compared to that in low and high hills can be attributed to difference in climatic and edaphic factors and leaching of bases from surface soil, which results in accumulation of H^+ ion in surface layer making soils more acidic. Higher organic carbon content in high and mid hills might be due to low soil organic matter decomposition rate (Wei *et al.* 2013). Slow process of litter decomposition and N mineralization in soil at high and mid hills due to relatively low temperature could probably lead high organic C and available major nutrients (N, P, and K) in the soil (Bonito *et al.* 2003). The higher status of P present in different hill zones could be attributed to fixation of phosphorus under acidic conditions. Whereas, less available K content at different locations might be due to less biomass addition as well as leaching of potassium under high rainfall conditions prevailing in the study area. Similar results for soils of Kangra district under different land uses had been reported by Shekhar (2011) and Sharma (2011).

Large variations in the species relative density in three hill zones were observed due to many factors, viz. slope, aspect, vegetation type, edaphic factors, and altitude (Sharma *et al.* 2010, Gairola *et al.* 2011), which decides the composition and structure of community and its distribution pattern (Dar *et al.* 2016). The structure and composition of the pasture in most mountains in the world is strongly influenced with altitudinal variations, soil fertility, climate and anthropogenic factors (Shaheen *et al.* 2011, McVicar and Korner 2012, Sharma *et al.* 2014). The diversity indices are a quantitative measures of species diversity in a community that shows how many different species are there in a population, and simultaneously takes into account how evenly each species are distributed in total population. In this study, the Simpson's index, Shannon diversity index, Menhinick index, Berger-Parker Dominance index, Gini Coefficient and Routlegde beta-R-index were observed higher in mid hills as compared to low hills and high hills. Diversity in pasture species may have complementarity for more efficient use of soil water, light and nutrients as compared to single plant community (Hector 1998) and could increase the pasture yield, improve yield stability and reduction in soil and nutrient loss (Sanderson *et al.* 2004). The average Shannon diversity index in the present study varied between 2.303 (Zone-I) to 2.339 (Zone-III), which are comparable to other studies in western Himalayan region (Shannon diversity index varied between 1.53 to 3.13; Guar and Joshi (2006), Shaheen *et al.* 2011). Presence of higher number of grass species in total community in mid hills resulted into higher values of diversity indices as compared to low and high hills. This may be due to the fact that mid hills are less disturbed than low hills and having favourable climatic conditions as compared to the high hills (Dar *et al.* 2016).

Favourable temperature and high rainfall in low hills may have attributed to the higher biomass yield than mid and high hills. Although, biomass potential of the higher hills seems to be insufficient for the flocks, but because of presence of higher legume component, livestock showed gain in weight (Dev *et al.* 2003). Among the different landuse systems, highest biomass production was recorded at well managed farmers' land followed by community land, enclosed forest and open forest. Biomass production in these locations were directly influenced by human interventions. Wasteland with relatively poor soil fertility and least interventions recorded the lowest biomass as compared to other landuse systems. The legume component was more in high hills and grasses in the high hills are leafy, less fibrous, nutritious and palatable as compared to mid hills and low hills. In single cut grasses, the leafy material is shattered down, become more lignified and yields less crude protein. The grasses get rejuvenated in multicut situation, yields more green biomass and more CP content. The high CP content at farmers' field may be due to better management of grasses. Since the white clover and red clover in the high hills get re-germinated regularly due to shattering of seed and produces green biomass, which might be the reason that there was not much difference in the CP content in the community land and farmers field. Perhaps, the farmers in the high hills consider equally their own land and community land and manage properly, because these are only sources for livestock production. Low forage production with high crude protein concentration from high hills was also reported by Singh *et al.* (2009) and vice-versa in lower hills by Pathania and Dev (2011). On an overall basis, the herbage biomass at high hills had better nutritive quality as compared to low and mid hills. High hills had higher leguminous species richness as compared to low and mid hills. Legume forages are good source of protein and other nutrients and can replace some part of concentrate feed (Sharma and Ghosh 1997, Kumar and Bhatt 1999). Biomass potential in multicut situation was much higher than the single cut at all the locations of three hill zones.

Management of grasslands through multicuts resulted in higher biomass production and better nutritive quality as compared to single harvest. High species richness as well as community diversity was found in mid hills as compared to low and high hills. The survey generated preliminary information based on which an extensive study can be taken up with the help of satellite imagery to develop geo-database providing precise information on spatial distribution of grassland resources in western Himalaya and similar geo-climatic regions. Taking the observations made in this study as reference, a new study on the relation between different vegetative indices and above ground biomass as well as terrestrial carbon storage can generate very useful information.

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