Tropical Ecology **43**(2): 325-335, 2002 ISSN 0564-3295

Phytosociology, primary production and nutrient retention in herbaceous vegetation of the forestry arboretum on the Aravalli hills at Jaipur

K.P. SHARMA[1] & B.P. UPADHYAYA[2]

[1]*Department of Botany, University of Rajasthan, Jaipur – 302004, India*
[2]*Department of Botany, M.M.A. Campus, Biratnagar, Tribhuvan University, Kathmandu, Nepal*

Abstract: Present study was made on the foot hill, slope (middle hill) and top of the protected and unprotected hills of the Aravalli at Jaipur (26° 49′N, 75° 48′E, 436 m.s.l.). Herbaceous vegetation was therophytic in nature, exhibiting maximum number of species during rainy season. The biomass of herbaceous vegetation at the unprotected hill sites (264-462 g m^{-2}) was higher than protected hill sites (201-338 g m^{-2}). Annual net primary production was: protected hill, 430-587 g m^{-2}; unprotected hill, 283-613 g m^{-2}. Nitrogen and phosphorus contents in the plant biomass varied from 2725-7723 mg m^{-2} and 364-795 mg m^{-2} respectively. The present study revealed an increase in the soil nutrients and species diversity at the protected hill and role of herbaceous vegetation in the conservation of nutrients at both hills.

Resumen: El presente estudio se llevó a cabo en el piedemonte, la pendiente media y la cima de las colinas protegidas y no protegidas de Aravalli, Jaipur (26° 49′N, 75° 48′E, 436 m s.n.m.). La vegetación herbácea tuvo una naturaleza terofítica y el número máximo de especies se mostró durante la estación lluviosa. La biomasa de la vegetación herbácea en los sitios no protegidos de las colinas (264-462 g m^{-2}) fue mayor que en los sitios protegidos (201-338 g m^{-2}). La producción primaria neta anual fue: colina protegida, 430-587 g m^{-2}; colina no protegida, 283-613 g m^{-2}. Los contenidos de nitrógeno y fósforo en la biomasa vegetal variaron de 2725-7723 mg m^{-2} a 364-795 mg m^{-2}, respectivamente. Este estudio reveló que existe un incremento en los nutrientes del suelo y en la diversidad de especies en las colinas protegidas, y mostró el papel de la vegetación herbácea en la conservación de los nutrientes en las colinas en ambas condiciones.

Resumo: O estudo presente foi efectuado no sopé, na encosta (a meio) e no topo de colinas protegidas e não protegidas do Aravalli em Jaipur (26º 49’ N, 75º 48’ E e 436 m.s.l). A vegetação herbácea era terofítica em natureza, exibindo um máximo número de espécies durante a estação chuvosa. A biomassa da vegetação herbácea nos locais desprotegidos das colinas (264 – 462 g m^{-2}) era mais elevada do que nas estações protegidas das colinas (201 – 338 g m^{-2}). A produção primária anual líquida foi de: colinas protegida, 430 – 587 g m^{-2}; colina não protegida, 283 – 613 g m^{-2}. O teor em azoto e fósforo na biomassa vegetal variou entre os 2725 – 7723 mg m^{-2} e os 364 – 795 mg m^{-2}, respectivamente. O estudo presente revelou um aumento nos nutrientes do solo e na diversidade específica na colina protegida e o papel da vegetação herbácea na conservação dos nutrientes nas duas colinas.

Key words: Annual net primary production, Aravalli hill, herbaceous vegetation, nutrient budget, protected hill, unprotected hill.

Introduction

The forest floor vegetation plays an important role in nutrient cycling, habitat conservation and regeneration of tree shrubs. The herbaceous floor vegetation has been reported to show high nutrient content and rapid turnover rates as influenced by climatic conditions (Spain 1984) and vegetation characteristics (Vogt & Vogt 1986). There are only few reports on the organic matter production of the ground vegetation in the forest ecosystems (Pradhan & Dash 1984; Singh & Singh 1980 and Vyas & Vyas 1978), with little information on phytosociology. The present study was aimed to analyze species composition, biomass, productivity and nutrient content of ground floor herbaceous vegetation of the forestry arboretum and an unprotected site on the Aravalli hills.

Study area

The study sites are located on Aravalli hills in Jaipur (26° 49′ N latitude and 75° 48′ longitude, 436 m above mean sea level). The continuous chain of hills of Aravalli ranges are of Pre-Cambrian age, having an average height of 500 m. A large amount of quaternary loose sand formed by weathering of local sand stones has sedimented along the longitudinal valleys and foot hills. The study sites selected for the present study are located at the Jhalana hill. The World Forestry Arboretum was established in the year 1986 in an area of about 1000 ha. About 70% of the area is a stabilized sand dune, while remaining is hilly slopes facing west. The arboretum has check dams to conserve soil and moisture in the valley. The steep hill slopes were initially covered with mulch of *Saccharum* and other herbaceous plants to conserve soil and moisture. Almost opposite to the hill slope lies a large stabilized sand dune (height = 50-100′), varying in distance from 100′ – 1000′. Due to marked differences in the topographic conditions, the vegetation composition was studied on the foot hill, middle hill and top hill. This represented a protected site free from cattle grazing and tree felling.

To analyze the effect of site protection on herbaceous vegetation, an unprotected hill site located 2 km from the protected hill was also selected. The hill slopes face western direction similar to protected hill. A large stabilized sand dune (70 – >100′ in height) lies almost opposite to this hill also at a distance of 100 – 200′. The herbaceous biomass including *Prosopis chilensis* twigs at the hill are harvested for fuel during autumn by the local inhabitants, while their cattles, especially goats, grazed throughout the year. The observations on the vegetation were recorded on the foot hill, middle hill and top hill was also artificially divided into three zones similar to the protected hill.

The climate of the study area is semi arid having three seasons summer, rainy and winter (Sharma & Gopal 1977). The summer months (April-June) are very hot, with maximum temperature touching up to 44°C. The rains begin in the end of June. About 89% of total rainfall (mean rainfall = 688 mm year^{-1}) occurs during June to September. The minimum temperature during winter remains close to freezing point.

Materials and methods

Phytosociological analysis of herbaceous vegetation was carried out on the 6 study sites, three each located in the protected and unprotected hill areas. The observations on frequency, density and basal areas of the plants were recorded by Quadrat method. Importance value indices of plant species of the herbaceous vegetation was calculated according to Cottam & Curtis (1956). Coefficient of Similarity (Sorenson's index) was calculated as follows:

$$Cs = \frac{2j}{a+b}$$

where, j is the number of species common to both habitats while a and b are the total number of species in habitat a and b respectively.

Trees, succulents and shrubs of the study area are given in Table 1.

The biomass of herbaceous vegetation (shoot only) was estimated at monthly intervals by harvest method. During active growing period (15th July 1991 to 30th August 1991), the shoot harvests were, however, made at fortnight intervals. At each harvest, first the litter was collected and then all shoots in a quadrat (50 x 50 cm) were harvested close to the ground level. The shoots were fractionated into live and standing dead. Each fraction was dried to constant weight at 80°C and its dry weight per unit area was calculated. The aboveground net primary productivity

Table 1. Composition of trees, succulents and shrubs at the study sites.

S.N. Plant species	Protected hill			Unprotected hill		
	Top	Mid	Foot	Top	Mid	Foot
Quadrat species						
1. *Acacia senegal* Willd	+	–	+	–	–	–
2. *Anogeissus pendula* Edgew.	+	+	+	–	–	–
3. *Ehretia laevis* Roxb.	–	+	+	–	–	–
4. *Euphorbia neriifolia* Linn.	+	+	–	–	–	–
5. *Grewia tenax* Fiori	–	+	+	–	–	–
6. *Maytenus emarginata* Ding-Hou	–	–	+	–	–	–
7. *Rhus mysurensis* Heyne	+	–	–	–	–	–
8. *Securinega leucopyrus* Muell. – Arg.	–	–	+	–	–	–
No. of woody species in quadrat study	4	4	6	Nil	Nil	Nil
Non-quadrat species						
9. *Barleria prionitis* Linn.	+	+	+	+	+	+
10. *Boswellia serrata* Roxb. Ex Colebi.	+	–	–	+	–	–
11. *Calotropis procera* R. Br.	+	+	+	+	+	+
12. *Capparis decidua* Edgew.	–	–	+	–	–	–
13. *Cocculus pendulus* Diels	+	+	–	–	–	–
14. *Commiphora wightii* (Arnott.) Bhandari	–	–	+	–	–	–
15. *Haplophragma adenophyllum* Seem. ex Benth. & Hooker	–	–	–	+	–	–
16. *Prosopis chilensis* (Molina) Stuntz	–	–	–	–	+	+
Number of non-quadrat species	4	3	4	4	3	3
Number of woody species present at the study site	8	7	10	4	3	4

+ = Present; – = absent

was computed using the "trough peak analysis" by summation of positive changes in live biomass and concurrent increase in live shoot biomass (Singh *et al.* 1975).

Three soil samples up to a depth of 10 cm were collected at monthly intervals from each of the six sites. These were dried in a hot air oven at 80°C, and then analyzed for their physico-chemical characteristics following methods described by Jackson (1967). Water holding capacity (WHC) of the soil samples were estimated using standard brass cup method (Piper 1957).

Tissue concentration of nitrogen and phosphorus in the plants were estimated by standard methods. The nutrient content in vegetation was computed by multiplying tissue concentration with the biomass.

Statistical analyses were made using Systat version 5.0.

Results and discussion

Soil characteristics

The soil was slightly alkaline (pH = 7.5 – 8.6) at both protected and unprotected hills. The values of water holding capacity (WHC), conductivity, organic carbon, total Kjeldahl nitrogen and exchangeable phosphorus were usually higher in the protected hill soil (Table 2).

The improvement in the soil cover and nutrient levels at the protected hill suggests better habitat conditions for plant growth. Pandey & Singh (1990) and Gibson & Kirkpatrick (1989) have reported such a recovery of soil nutrient status in successional grasslands and woodlands.

Phytosociological studies

78 plant species, 17 of monocots and 61 of dicots, were recorded on the two hills (Table 1 and

Table 2. Characteristics of the soil at the study sites.

Parameters	Protected hill			Unprotected hill		
	Top	Mid	Foot	Top	Mid	Foot
pH	7.6 – 8.2	7.6 – 8.2	7.5 – 8.3	7.6 – 7.9	7.2 – 7.9	8.3 – 8.7
WHC* (%)	40 – 50	9 – 47	32 – 37	31 – 40	36 – 41	28 – 32
Conductivity (m mho cm^{-1})	0.019 – 0.159	0.033 – 0.139	0.06 – 0.17	0.05 – 0.14	0.03 – 0.19	0.04 – 0.16
Organic carbon (%)	0.23 – 1.16	0.40 – 2.01	0.54 – 2.24	0.35 – 1.28	0.50 – 2.44	0.46 – 2.38
Total N (%)	0.30 – 1.20	0.70 – 2.10	0.95 – 2.55	0.30 – 1.60	0.50 – 1.50	0.35 – 1.45
Available P (mg 100 g^{-1})	0.20 – 1.87	0.05 – 1.23	0.10 – 0.90	0.13 – 1.40	0.07 – 1.07	0.07 – 0.37

* WHC = Water holding capacity

Appendix I). Amongst them, 8 woody species were not encountered during quadrat study on account of their sparse distribution at the study sites (Table 1). The species richness of the protected hill (Herbaceous = 50; Woody = 14; Total 64) was higher than unprotected hill (Herbaceous = 45; Woody = 5; Total = 50), though number of herbaceous species at different sites of these hills was almost equal (Protected = 32 – 37; Unprotected – 32 – 35) on account of difference in their distribution pattern. It is thus evident that diversity of woody species was relatively higher on the protected hill (14) in comparison to unprotected hill (5) (Table 1). Only two native species of tree, *Boswellia* (about 2' tall) and *Haplophragma* (5-8" tall) were seen in a highly degraded state on the top hill site of unprotected hill. Further, the colonization of an exotic tree species *Prosopis chilensis* was observed on the foot and mid hill sites.

Maximum number of herbaceous plant species on both protected (50) and unprotected (45) hills were recorded during rainy season, while their minimum number were recorded in the winter (Protected = 2 – 8; unprotected = 4 – 6) and summer (Protected = 1 – 6; Unprotected = 4 – 6) seasons. Availability of moisture during rainy season favored occurrence of most of the herbaceous plant species, especially therophytes, on account of semi arid climate of the study area (Table 3).

Table 3. Biological spectrum of vegetation on the study sites at Jhalana hill.

Life forms	Protected hill			Unprotected hill		
	Top	Mid	Foot	Top	Mid	Foot
Phanerophytes	11.1	8.9	18.2	5.0	2.7	2.8
Chamaephytes	11.1	11.1	15.9	15.0	16.2	13.9
Hemicryptophytes	15.5	17.8	20.4	15.0	24.3	25.0
Cryptophytes	2.2	4.4	4.5	2.5	0.0	5.5
Therophytes	60.0	57.8	40.9	62.5	56.7	52.7

The dicots (Protected = 33 – 36; Unprotected = 25 – 30) out numbered monocots (Protected = 6 – 11; Unprotected = 7 – 10) at all the sites of both hills, being higher in number at the protected hill (Appendix I). It may be on account of the fact that most of the monocots, especially grasses, are surface feeder.

Floristic composition of herbaceous as well woody vegetation of both hills differed markedly. 17 herbaceous and 11 woody plant species were confined only to the protected hill (Table 1 & Appendix I), while numbers of plant species restricted to the unprotected hills sites were relatively lower (Herbaceous = 12; Woody = 2). The loss in biodiversity at the unprotected hill may be related to the poor habitat conditions and increased biotic pressure.

A perusal of Sorenson coefficient (Sc) values revealed marked difference in the distribution of plant species between two hills (Sc = 0.32) as well as on their different sites (Table 4). Only about 20 – 37% species were common at the study sites.

Table 4. Sorenson coefficient for the vegetation at the study sites.

Site	Protected hill			Unprotected hill		
	Top	Mid	Foot	Top	Mid	Foot
1	1	0.37	0.28	0.28	0.28	0.27
2		1	0.32	0.29	0.30	0.25
3			1	0.25	0.20	0.21
4				1	0.36	0.35
5					1	0.37
6						1

In grassland communities, topography, edaphic factors and disturbances produce regional variations in composition and structure of vegetation (Belsky 1988; Gibson & Hulbert 1987). These same factors increase diversity and heterogeneity within communities as well (Milchunus *et al.* 1988). In the present study also, all these three factors were perhaps responsible for difference in the composition and structure of vegetation on the protected and unprotected hill sites.

During rainy season, forbs were dominant (IVI = 208), while grasses were codominant (IVI = 74.5) on the top hill site of protected hill (Table 5). The IVI of forbs (145) and grasses (126 – 140) were, however, almost equal at the mid and foot hill sites of protected hill. In the unprotected hill, grasses (IVI = 163) were dominant on the top hill site, while forbs (IVI = 142 – 157) on the mid and foot hill sites. These variations in the dominance of plant types are perhaps associated with the microclimate and edaphic conditions at the study sites, and require further investigation. Based on IVI, following associations of plant species were characterised.

Protected hill

1 – Top hill
Borreria – Bidens – Vernonia – Apluda
2 – Mid hill
Apluda – Borreria – Cenchrus setigerus – Digitaria
3 – Foot hill
Cenchrus penisetiformis - Heteropogon – Dipterocanthus – Borreria

Unprotected hill

1 – Top hill
Aristida – Dichanthium - Dipterocanthus – Borreria
2 – Mid hill
Tephrosia apollinea - Dipterocanths – Aristida – Dichanthium
3 – Foot hill
Lepidagathis – Cenchrus biflorus – Aristida – Tephrosia apollinea

During summer and winter, grasses were absent and the dominant component of herbaceous vegetation comprised of forbs and legumes only. The dominant species on the protected hill sites were *Hibiscus, Peristrophe, Pupalia* and *Tephrosia subruifolia*, whereas on unprotected hill, these were *Dipterocanthus, Lepidagathis, Lindenbergia, Pupalia* and *T. apollinea.* Thus the dominant plant species differed between the hills as well as between different sites of the same hill. Joshi *et al.* (1990) also found shift in dominant species types based on their IVI values in the foot hill, slope and top hill. Their dominance at the specific sites was possibly on account of availability of optimum conditions for their growth. Distribution of the plant species has been correlated with the nutrient status of the soil. Legumes are reported to grow preferably in areas with low organic matter content in the soil (Holter 1979). Relatively lower level of organic carbon at the unprotected hill sites, therefore, favoured higher dominance of legumes in comparison to the protected hill sites (Tables 2 & 5).

Table 5. Importance value index of herbaceous vegetation at the study sites during rainy season.

Sites	Importance value index		
	Grasses	Legumes	Forbs
Protected sites			
Top hill	74.5	16.9	207.7
Middle hill	125.9	28.5	145.7
Foot hill	139.7	14.6	144.0
Unprotected sites			
Top hill	163.5	36.7	99.7
Middle hill	107.1	50.3	142.1
Foot hill	104.6	35.0	157.1

Biomass and primary production

Availability of moisture during rainy season favoured rapid increase in the standing crops of herbaceous vegetation at both protected and unprotected hills, which attained peak in the post rainy season (Figs. 1-6). Others also made similar observations (Joshi *et al.* 1990; Pradhan & Dash 1984; Singh & Singh 1980; Vyas & Vyas 1978).

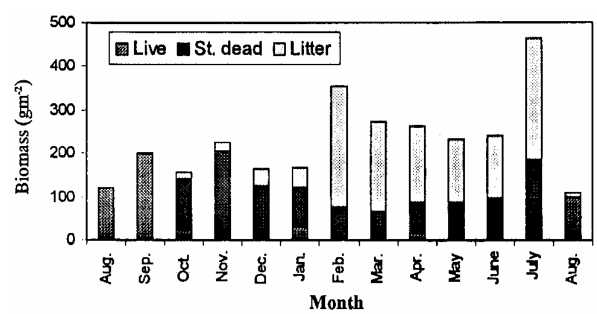

Fig. 1. Monthly variations in the aboveground biomass and litter of herbaceous vegetation at top hill site of protected hill.

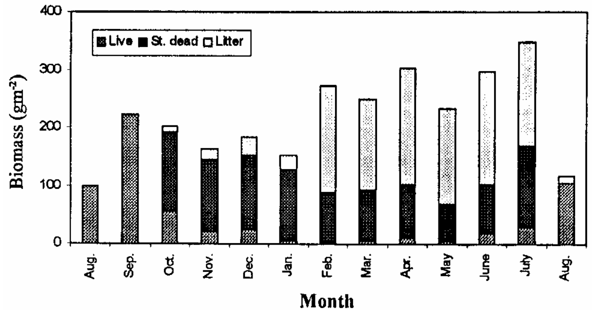

Fig. 2. Monthly variations in the aboveground biomass of herbaceous vegetation at mid hill site of protected hill.

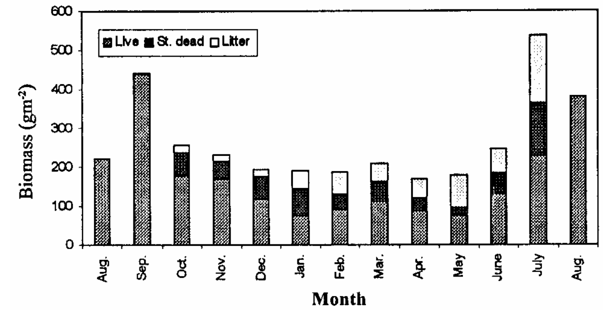

Fig. 5. Monthly variations in the aboveground biomass of herbaceous vegetation at mid hill site of unprotected hill.

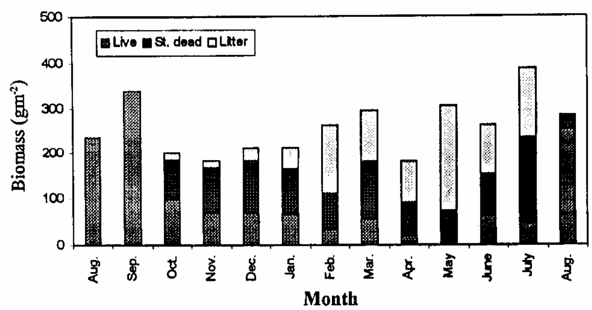

Fig. 3. Monthly variations in the aboveground biomass of herbaceous vegetation at foot hill site of protected hill.

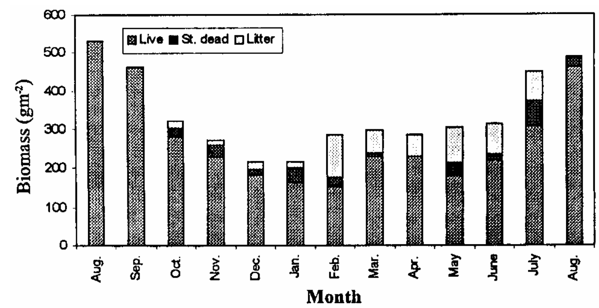

Fig. 6. Monthly variations in the aboveground biomass of herbaceous vegetation at foot hill site of unprotected hill.

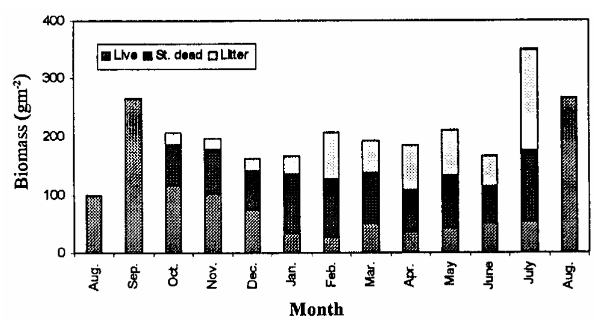

Fig. 4. Monthly variations in the aboveground biomass of herbaceous vegetation at top hill site of unprotected hill.

The peak standing crops of the herbaceous vegetation at the protected hill were lower than unprotected hill (significant at 6% probability; Table 6), despite of availability of more nutrients in the soil (Figs. 1-6). This was not caused by shade of trees and shrubs, as herbaceous vegetation grew only in the open areas and was almost completely absent below the tree cover. This may be on account of difference in species composition as described earlier, and also seems to be regulated by the tree litter, which has been found to have more direct damaging effects (physical and chemical) upon herbaceous vegetation (Sydes & Grimes 1981).

The differences in the standing crops of herbaceous vegetation between three sites of the protected hill and also between top and middle hill sites of both hills were insignificant statistically, while they were significant between three sites of unprotected hill and foot hill sites of both hills (Table 6). Thus, the biotic disturbances have markedly affected production structure of herbaceous vegetation at the unprotected hill, especially its foot hill site.

The forbs and grasses were the major primary producers at the study sites, as they contributed maximum (45 – 61%) to the peak standing crops of herbaceous vegetation. Legumes contributed maximum at only unprotected mid hill (49%).

Table 6. Student 't' test for standing crops of herbaceous vegetation on the hills.

Treatments	t	df	Probability
Protected hill vs. Unprotected hill	– 1.915	38	0.06
Protected top hill vs. Protected mid hill	1.038	12	0.32
Protected top hill vs. Protected foot hill	– 1.021	12	0.32
Protected foot hill vs. Protected mid hill	1.446	12	0.17
Unprotected top hill vs. Unprotected mid hill	– 3.031**	12	0.01
Unprotected mid hill vs. Unprotected foot hill	– 3.041**	12	0.01
Unprotected top hill vs. Unprotected foot hill	– 4.848**	12	0.00
Unprotected top hill vs. Protected top hill	– 1.316	12	0.21
Unprotected mid hill vs. Protected mid hill	1.369	12	0.19
Unprotected foot hill vs. Protected foot hill	3.416**	12	0.005

**Significant at 1% probability

A comparison of peak standing crops of the herbaceous vegetation in the present study with that others revealed their higher values (Joshi *et al.* 1980; Pradhan & Dash 1984; Singh & Singh 1980). This may be due to difference in the species composition at the study sites. The standing crops of herbaceous vegetation at the protected hill are, however, comparable to that on the protected Aravalli hill in Udaipur (Vyas & Vyas 1978).

Annual net primary production (ANPP) of herbaceous vegetation at the protected hill was higher than unprotected hill, except for mid hill site of the latter (Table 7). This may be due to contamination of litter with tree litter at the protected hill. ANPP values of herbaceous vegetation of the protected Aravalli hill at Udaipur (211.4 – 375.0 g m^{-2}) are lower than the values for protected hill sites in the present study (Vyas & Vyas 1978). This may be due to difference in the species composition.

In both protected and unprotected hills, standing crops of the herbaceous vegetation were maximum on the foot hill sites, similar to observations made by Vyas & Vyas (1978) and Pradhan & Dash (1984). Vyas & Vyas (1978) suggested this on account of better moisture and nutritional status of the soil at the foot hill. Pradhan & Dash (1984), however, argued this on account of high species diversity at the bottom (foot hill) than at the hill top. In the present study, these seem to be on account of availability of more soil moisture to the vegetation on the foot hill including occurrence of perennial species such as *Tephrosia apollinea* in higher proportion. The high soil moisture at the foot hill sites may be due to relatively less exposure of foot hill vegetation to both direct sunlight and wind in comparison to mid and top hill sites, resulting in less evapotranspiration from the foot hill region.

The primary productivity of the herbaceous vegetation was lower at both protected (1.18 – 1.60

Table 7. Net primary productivity of herbaceous vegetation at the study sites.

Sites	Net Primary Productivity (g m^{-2} Yr^{-1})	
	Rainy season	Annual
Protected sites		
Top hill	212.6	587.0
Middle hill	166.6	430.5
Foot hill	397.6	457.7
Unprotected sites		
Top hill	243.2	417.1
Middle hill	171.6	613.7
Foot hill	153.4	283.7

Table 8. Peak standing crops of nitrogen and phosphorus in the herbaceous biomass at the study sites.

Sites	Standing crop (mg m^{-2})	
	N	P
Protected sites		
Top hill	3247	739
Middle hill	2725	364
Foot hill	4584	583
Unprotected sites		
Top hill	3437	542
Middle hill	7326	795
Foot hill	7723	620

g m^{-2}) and unprotected (0.77 – 1.68 g m^{-2}) hills based on their annual growth, but increased to about 3 – 5 folds (Protected = 3.61 – 8.64 g m^{-2} d^{-1}; Unprotected hill = 3.33 – 5.28 g m^{-2} d^{-1}) when calculated for active growing period (rainy season). With the exception of unprotected foot hill (0.77 g m^{-2}), the primary productivity of the both hills were higher than ground vegetation of dry deciduous forest (0.82 – 0.98 g m^{-2} d^{-1}, Singh & Singh 1980). Its values for active growing period were almost similar to alpine grassland (4.2 g m^{-2} d^{-1}), but lower than temperate grassland (10.4 g m^{-2} d^{-1}) (Sah & Ram 1989). This suggests that herbaceous vegetation of Aravalli was quite productive.

In the present study, the bulk of live biomass was transferred to the standing dead and litter after September, as majorities of the plant species growing in the communities were therophytes (Figs. 1-6). Other workers (Joshi *et al.* 1988; Pradhan & Dash 1984; Singh & Singh 1980) made almost similar observations. Litter biomass was maximum in the winter, becoming nil during rainy season due to its decomposition as well as loss with run off water.

Nitrogen and phosphorus content in vegetation

Standing crops of nitrogen (N) and phosphorus (P) were higher in the herbaceous vegetation of unprotected hill, being maximum in the month of September, which coincided with their peak biomass (Table 7). Forbs (N = 44 – 60%; P = 54 – 68%) and grasses (N = 31 – 39%; P = 45 – 53%) were the major contributors to the peak standing crops of N and P. Legumes contributed maximum only at the foot (N = 49%; P = 27%) and mid hill (N = 64%; P = 43%) sites of the unprotected hill.

Conclusions

The present study revealed dominance of grasses and forbs in the forest floor vegetation of the Aravalli hill ecosystem. Although both protected and unprotected hills differed little in species richness of herbs, but woody species were certainly higher in number on the protected hill. Both biomass and primary productivity of herbaceous vegetation at the unprotected hill were, however, higher than protected hill despite of availability of more nutrient in the soil in the latter. Herbaceous vegetation helped in the conservation of nutrients, especially at the unprotected hill sites, where it formed the major component of overall vegetation. The study also revealed regeneration of native woody species at the protected hill, following relaxation of biotic pressure and conservation of soil and moisture. Therefore, this model may be used to restore natural vegetation in the degraded Aravalli ecosystem.

Acknowledgements

One of us (KP) is grateful to the Department of Science and Technology, New Delhi, for providing financial support. We thank the Head, Botany Department, University of Rajasthan, Jaipur, for the laboratory facilities, Mr. Roop Singh, Curator, Herbarium Section for plant identification and the Rajasthan State Forest Department, Jaipur for their cooperation in conducting the present study.

References

Belsky, A.J. 1988. Regional influence on small scale vegetational heterogeneity within grasslands in the Serengeti National Park, Tanzania. *Vegetatio* **74**: 7-10.

Cottam, G. & J.T. Curtis. 1956. The use of distance measures in phytosociological sampling. *Ecology* **37**: 451-460.

Gibson, N. & L.C. Hulbert. 1987. Effects of fire, topography and year to year climatic variation on the species composition in tall grass prairie. *Vegetatio* **72**: 175-185.

Gibosn, N. & J.B. Kirkpatrick. 1989. Effects of cessation of grazing on the grassland and grassy woodlands of the central plateau, Tasmania. *Australian Journal of Botany* **37**: 55-63.

Holter, V. 1979. Distribution of leguminosae in early stages in relation to edaphic factors. *Botanisk Tidsskrift* **74**: 79-87.

Jackson, M.L. 1967. *Soil Chemical Analysis*. Prentice Hall India Pvt. Ltd., New Delhi.

Joshi, S.P., A. Raizada & M.M. Srivastava. 1988. Net primary productivity of a high altitude grassland in Garhwal, Himalaya. *Tropical Ecology* **29**: 15-20.

Joshi, S.K., D.P. Pati & N. Behera. 1990. Primary production of herbaceous layer in a tropical deciduous forest in Orissa, India. *Tropical Ecology* **31**: 73-83.

Milchunas, D.G., D.E. Sala & W.K. Lauenroth. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. *American Naturalist* **132**: 87-106.

Pandey, H.N. & R.N. Singh. 1990. Nitrogen storage and cycling in early successional stages of a grassland community at Varanasi, India. *Tropical Ecology* **31**: 75-81.

Piper, C.S. 1957. *Soil and Plant Analysis*. Hans Publishers, Bombay.

Pradhan, G.B. & M.C. Dash. 1984. Seasonal variation in plant biomass and net primary productivity of a Savanna type hill ecosystem of Sambalpur, India. *Tropical Ecology* **25**: 172-178.

Sah, V.K. & Jeet Ram. 1989. Biomass dynamics, species diversity and net primary production in a temperate grassland of Central Himalaya, India. *Tropical Ecology* **30**: 294-302.

Sharma, K.P. & B. Gopal. 1977. Studies on stand structure and primary production in *Typha* species. *International Journal Ecology and Environmental Sciences* **3**: 45-66.

Singh, J.S., W.K. Lauenroth & R.K. Steinhorst. 1975. Review and assessment of various techniques for estimating net aerial primary production in grassland from harvest data. *Botanical Review* **41**: 181-232.

Singh, K.P. & R.P. Singh. 1980. Biomass and net production of herbaceous layer in tropical dry deciduous forest at Varanasi. *Tropical Ecolgoy* **21**: 47-58.

Spain, A.V. 1984. Litter fall and the standing crop of litter in three tropical Australian rain forests. *Journal of Ecology* **72**: 947-961.

Sydes, C. & J.P. Grime. 1981. Effects of tree litter on herbaceous vegetation in deciduous woodland. I. Field investigations. *Journal of Ecology* **69**: 237-248.

Vogt, K.A. & D.J. Vogt. 1986. Production, turnover and nutrient dynamics of above and belowground detritus of world forest. *Advances in Ecological Research* **15**: 303-377.

Vyas, L.N. & N.L. Vyas. 1978. Net primary production of *Apluda* community on Aravalli hills at Udaipur. pp. 111-124. *In*: J.S. Singh & B. Gopal (eds.) *Glimpses of Ecology*. International Scientific Publisher, Jaipur.

Appendix 1. Distribution and life form of herbaceous species at the study sites.

S.N.	Plant species	Life form	Protected hill			Unprotected hill		
			Top	Mid	Foot	Top	Mid	Foot
Grasses								
1.	*Acrachne racemosa* (Heyne) Ohwi	Th	+	+	–	+	+	+
2.	*Apluda mutica* Linn.	He	+	+	+	–	–	–
3.	*Aristida adscensionis* L.	Th	+	+	–	+	+	+
4.	*Bothriochloa ramosa* (L.) A. Camus.	Cr	–	–	–	+	–	+
5.	*Brachiaria ramosa* (L.) Stapf.	Th	+	+	+	+	+	+
6.	*Cenchrus biflorus* Roxb.	Th	–	–	–	+	+	+
7.	*C. penisetiformis* Hochst. et Steud. ex Steud.	Cr	–	+	+	–	–	–
8.	*C. setigerus* Vahl.	Cr	–	+	+	–	–	–
9.	*Cyperus arenarius* Retz.	Cr	+	–	–	–	–	+
10.	*C. triceps* Endl.	He	+	+	–	–	–	–
11.	*Dichanthium annulatum* Stapf.	Ch	–	–	–	+	+	+
12.	*Digitaria adscendens* Henr.	He	+	+	–	+	+	+
13.	*D. pennata* T. Cooke	Ch	–	+	–	–	–	–
14.	*Heteropogon contortus* Roem. & Schult	He	–	–	+	–	–	–
15.	*Melanocenchris jacquemontii* Jaub. et Spach.	Th	–	+	–	+	–	+
16.	*Sporobolus diander* Beauv.	Th	+	+	+	+	–	–
17.	*Tetrapogon tenellus* Schult.	Th	–	–	–	+	+	+
Legumes								
18.	*Alysicarpus vaginalis* DC.	Th	–	+	+	+	+	–
19.	*Cassia pumila* Lamk.	Th	+	+	–	–	+	+
20.	*Indigofera cardifolia* Heyne ex Roth	Th	+	+	–	+	–	+
21.	*Rhynchosia pulverulenta* Stocks in Hook.	Th	+	–	–	+	–	+
22.	*Tephrosia apollinea* Link.	Ch	–	–	+	–	+	+
23.	*T. subtriflora* Hochst. ex Baker	Ch	+	+	+	+	+	–
24.	*T. strigosa* Santapau & Mahesh.	Th	+	+	–	+	+	–
25.	*Vigna trilobata* Linn.	Th	+	+	+	+	+	+
26.	*Zornia gibbosa* Span.	Th	–	–	–	+	–	–
Forbs								
27.	*Aerva tomentosa* Forsk.	Ch	–	–	+	–	–	–
28.	*Bidens biternata* Merr. & Sherff	Th	+	+	+	+	+	+
29.	*Boerhavia diffusa* Linn.	He	–	+	+	+	+	–
30.	*Blainvillea acmella* Phillipson	Th	–	–	–	+	+	–
31.	*Borreria stricta* Schum.	Th	+	+	+	+	+	+
32.	*Catharanthus pusillus* G. Don	Th	–	+	+	+	–	–
33.	*Cleome viscosa* Linn.	Th	+	+	+	–	+	–
34.	*Commelina forskalii* Vahl.	Th	+	+	+	+	+	–
35.	*Corchorus tridens* Linn.	Th	–	–	+	–	–	–

+ = Present; – = absent; Ch = Chamaephyte; Cr = Cryptophyte; He = Hemicryptophyte; Th = Therophyte.

contd…

Appendix 1. *contd...*

S.N.	Plant species	Life form	Protected hill			Unprotected hill		
			Top	Mid	Foot	Top	Mid	Foot
36.	*Cucumis setosus* Cogn.	Th	+	–	–	–	–	–
37.	*Dipteracanthus patulus* Nees	He	–	–	–	+	+	+
38.	*Euphorbia hirta* Linn.	Th	+	+	–	–	–	–
39.	*Evolvulus alsinoides* Linn.	He	+	+	+	–	–	–
40.	*Hibiscus micranthus* L.	Ch	+	–	+	–	–	–
41.	*Ipomoea* sp.	Th	+	+	+	+	+	–
42.	*I. pes-tigridis* Linn.	Th	+	+	+	+	+	+
43.	*Lepidagathis trinervis* Wall. ex. Nees	He	–	–	–	–	+	+
44.	*Leucas utricaefolia* J. Donn	Th	+	+	–	–	–	–
45.	*Lindenbergia muraria* P. Bruehl	He	–	–	–	+	+	+
46.	*Mukia maderaspatana* M. Roem.	Th	+	–	+	+	–	+
47.	*Ocimum canum* Sims.	Th	+	+	–	–	–	–
48.	*Pavonia zeylanica* Cav.	Ch	–	–	–	+	+	+
49.	*Pedalium murex* Linn.	Th	–	+	–	+	+	+
50.	*Peristrophe bicalyculata* Nees	He	+	+	+	–	+	+
51.	*Phyllanthus asperulatus* Hutch	Th	+	+	+	–	+	+
52.	*Physalis minima* Linn.	Th	+	–	–	–	–	–
53.	*Portulaca suffruticosa* Wt.	He	–	–	–	–	–	+
54.	*Pulicaria angustifolia* Dc.	Th	–	–	+	–	–	–
55.	*Pupalia lappacea* Juss.	He	+	+	+	+	+	+
56.	*Rungia pectinata* Nees	He	–	–	+	–	–	–
57.	*Sclerocarpus africanus* Jacq.	Th	+	+	–	–	+	–
58.	*Striga gesnerioides* Willd.	He	–	–	–	–	+	–
59.	*Trichodesma indicum* Cooke	Th	+	–	+	+	+	+
60.	*Triumfetta rhomboidea* Jacq.	Th	+	+	+	+	+	+
61.	*Tridax procumbens* Linn.	He	+	+	+	+	+	+
62.	*Vernonia cinerea* Less.	Th	+	+	+	+	–	+
Total herbaceous species			36	37	32	35	34	32

+ = Present; – = absent; Ch = Chamaephyte; Cr = Cryptophyte; He = Hemicryptophyte; Th = Therophyte.