Effect of tree canopy on species composition, diversity and biomass of herbaceous vegetation and soil characteristics in semi-arid forests of the Aravalli hills

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Research

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Abstract

Background: Herbaceous vegetation is of great ecological importance and responds quickly to environmental changes. Present study was aimed to understand the variation in herbaceous species composition, diversity, biomass and soil physicochemical properties in canopy gaps and under the canopy of semi-arid forests in the Aravalli hills.

Methods: Four permanent plots consisting of canopy gaps and under canopy were established. To study herbs phytosociological attributes and biomass, 10 quadrats of 0.5 x 0.5 m size were laid in each plot. For soil physico-chemical properties, 5 soil samples were collected randomly at 0-10 cm depth from each plot. Relationship between biodiversity indices, herbs biomass and soil physicochemical properties was determined using Redundancy Analysis (RDA) and correlation analyses.

Results: The sites differed in terms of herbaceous species composition, diversity, biomass and soil physico-chemical properties. Canopy gaps were dominated by grasses while forbs were higher under the canopy. Across the sites, *poaceae* was the dominant family. All species showed contagious distribution pattern. *Oplismenus burmannii* reported highest IVI (138.0; 230.5) under the canopy while *Achyranthes aspera* (56.15) and *Eragrostis ciliaris* (53.1) had highest IVI in canopy gaps. Diversity indices were higher in canopy gaps. Herbaceous community biomass in canopy gaps ranged from 700-900 gm^{-2} while under the canopy it ranged from 30-70 gm^{-2}. *Cenchrus ciliaris* (597.97 gm^{-2}) and *Chrysopogon* sp. (391.2 gm^{-2}) constituted major proportion of biomass in canopy gaps. The soil of under canopy regions had lower pH and bulk density, but higher soil moisture (%), electrical conductivity, soil organic carbon (SOC), soil total nitrogen (TN), SOC stock and soil TN stock than the canopy gaps. Linear positive relationship between species diversity and biomass; negative relationship between soil chemical properties and herbaceous biomass was found in study area. Even though canopy had positive effects on soil physico-chemical properties, overall negative effect on herbaceous diversity and biomass was seen.

Conclusions: Reduced light for photosynthesis and tree root competition for soil resources may be the major factors negatively affecting herbaceous diversity and biomass. Canopy had a significant impact and herbs species composition, diversity, biomass and soil physico-chemical properties showed distinct differences in relation to it.

Background

Understory vegetation constitutes a major proportion of plant biodiversity in forest ecosystems (Gilliam 2007; Su et al. 2019). Although it comprises a small proportion of forest biomass, it plays a significant role in nutrient cycling and energy flow in forest ecosystems (Garkoti and Singh 1997; Gilliam 2007; Su et al. 2019). Many understory species are well-known indicators of climate as well as site characteristics and could act as an ecological indicator of ecosystem health, forest sustainability and conservation status (Chavez and Macdonald 2012). Tree canopies alter the abiotic environment for understory vegetation directly by affecting light availability, temperature, humidity, etc. and indirectly by influencing soil processes (Valladares et al. 2016). Canopy alters micro environmental conditions in terms of reduced air and soil temperature, wind speed and irradiation, resulting in decreased soil evaporation and increased relative humidity (Sagar et al 2010). The interception of solar radiation is a major factor affecting the understory (Hardwick et al., 2015). Canopy is the key regulator of solar radiation absorption and can prevent over 95% of light radiation from reaching the Earth's surface (Ishii et al., 2013).y Plants under the tree canopy are benefitted by increased organic matter and moisture in the soil, wind protection, reduced air, and soil temperature, reduced daily oscillations of temperature, increased humidity, lower water vapor deficit and reduced transpiration (Valladares et al. 2016: Kumar et al. 2020). However, the negative effects of tree canopy also exist, such as reduced light availability for photosynthesis, tree root competition for water and soil nutrients, allelopathic effects of trees, increased phytophagous fungi and pests and rainfall interception (Garkoti and Singh 1995; Valladares et al. 2016).

Delhi ridge constitutes the northern most limit of the Aravalli mountain systems (Meena 2019). It comprises semi-arid open scrub forests (Sinha, 2014). The vegetation comprises of thorny trees having scattered distribution interspersed with open patches (Meena 2019). A number of studies on herbaceous communities have been carried out in the region, most of them have focused on floristic diversity (Mishra at al. 2015, Dwivedi et al. 2018), phytosociological attributes (Krishna et al. 2014; Sharma & Upadhyay 2002; Gaury and Devi 2017) and understorey biomass carbon storage (Meena et al. 2019). However, no information is available on the influence of canopy and soil-physicochemical properties on herbaceous species diversity and biomass in a semi-arid region of India. Therefore, in present study we estimated the herbaceous species diversity, biomass and soil physico-chemical properties in canopy gap and under the canopy in a semi-arid forest ecosystem northern part of Aravalli hills, India.

We hypothesized that the diversity, composition, biomass of herbaceous species and soil physico-chemical properties in the canopy gaps and under the canopy will be different due to the differences of micro-climatic condition. The specific objectives of the study were to assess: (1) the effect of canopy on soil physico-chemical properties and soil C & N stocks (2) the variation in species composition, diversity and biomass of herbaceous species and their relation to the soil physico-chemical properties in canopy gaps and under the canopy.

Methods

Study area

The study area (Fig.1) is located in the southern part of New Delhi, at 28° 32'44. 88"N; 77° 10'13.08"E and comes under the region of South Central Delhi ridge which is northern most part of Aravalli hills (Sinha 2014, Meena 2016). The Ridge forest falls in the category of 'Tropical Thorn Forest' and more especially as 'Semi-Arid Open Scrub' (Champion and Seth, 1968). The climate of Delhi is semiarid; the average annual rainfall being 79 cm (Meena 2019). Delhi's mean annual temperature varies from 4°C to 46°C (Mishra 2015). South Central Delhi Ridge falls in the Kohi or Pahari physiographic region which is highly rocky and has undulating topography with a varied elevation from 2.5 meters to 90 meters above the plains. It is mostly composed of bare and unconsolidated

micaceous rocks (Sinha, 2014). Its soil is mainly dry and sandy, lacking humus and supporting sparse vegetation (Sinha, 2014). The Indian State of Forest Report, 2015, published by FSI records a total of 299.77 km^2 of forest and tree cover in Delhi, which accounts to 20.22% of its geographical area.

The ridge harbors a wide variety of trees, shrubs, and herb species. Amongst the most common native trees are Babul (*Acacia nilotica* var. *indica* (Benth) A.F.Hill), Phulahi (*Acacia modesta* Wall.), Katha (*Acacia catechu* Willd.), Ronjh (*Acacia leucophloea* (Roxb.) Willd.), Ber (*Ziziphus mauritiana* Lam.), Amaltash (*Cassia fistula* L.), *Capparis decidua* (Forssk.) Edgew., *Ficus virens* Aiton, *Syzygium cumini* (L.) Skeels, *Butea monosperma* (Lam.) Taub. (Dhak) etc. Noteworthy invasive tree species found is *Prosopis juliflora* (Sw.) DC. (Vilayati Babul). The common shrubs are Bansa (*Adhatoda vasica* L.) and Heens (*Capparis sepiaria* L.), *Grewia tentax* (Forssk.) Fiori, *Lantana camara*, Jangli karaunda (*Carisa spinarum* L.), etc. Herbaceous flora constitutes of *Calotropis procera* (Aiton) W. T. Aiton, *Withania somnifera* (L.) Dunal, *Achyranthes aspera* L., *Tridax procumbens* (L.) L., etc. Grass species found is *Cynodon dactylon* (L.) Pers., *Cenchrus ciliaris* L., *Dichanthium annulatum* (Forssk.) Stapf., *Eragrostis*, *Setaria verticillata* (L.) P. Beauv., etc.

Sampling design, data collection, and laboratory analysis

After reconnaissance and field observations, two representative sites on the campus were chosen for the study: Site 1: Parth Sarthi Rocks (PSR); Site 2: Poorvanchal (PRV). At each site, soil and herbaceous communities of both canopy gaps (CG) and under canopy (UC) areas were studied. The study area was divided into four permanent plots, viz., PSR CG, PSR UC, PRV CG, and PRV UC and phytosociological study was conducted during September 2019 using 10 random quadrats of 0.5 m x 0.5 m size. Soil sampling was done randomly with a metallic tube 50 cm high and 5 cm in diameter. After removing the litter layer carefully by hand, 5 samples from each of the four plots were collected at 0-10 cm depth. The samples were collected in zip lock bags, labeled and brought to the laboratory. Before the physicochemical analyses, all soil samples were air-dried and then sieved through a 2 mm sieve to remove the stones, litter, and plant roots.

For soil bulk density, soil samples were collected separately. Five soil samples were collected from each of the 4 permanent plots using cylindrical soil corer of diameter 5 cm and height 50 cm from the depth of 0-10 cm. The samples were then brought to the laboratory, sieved (2 mm) and oven-dried.

For biomass estimation of the herbaceous vegetation, aboveground and belowground parts of the plants were separated, cleaned and wrapped together in paper and labeled. The samples were then kept in oven at 65 °C till constant weight. Dry weight was then taken.

Soil moisture (%) was measured gravimetrically as the percent weight of water lost after the fresh soil sample was oven-dried. For this, 20g (W1) of fresh soil sample was weighed in a beaker. It was then oven dried at 105°C till constant weight was attained. The samples were weighed again (W2). Soil moisture (%) was calculated using following formula:

$$\frac{W1 - W2}{W2} \text{x } 100\% \qquad (1)$$

Soil bulk density by core sampling was determined (Lichter and Costello, 1994) using the following formula:

$$BD = \frac{W}{CV - \frac{CF}{PD}} \qquad (2)$$

In equation (2), BD is the bulk density of the < 2mm fraction (g cm^{-3}), W is the oven dry mass of fine fraction < 2mm in gram, CV is core volume (cm^3) = 785 cm^3, CF is mass of the coarse fragment (> 2mm) in gram, PD is density of rock fragment or particle density given as 2.65 g cm^{-3}. Core volume is calculated as πr2h where, r is the radius of the cylindrical core = 5 cm, h is depth of soil taken = 10cm.

The soil texture was measured using the sieving method (Gee and Or 2002). Soil pH was measured using control dynamics pH meter (Rhoades 1982). The soil to distilled water ratio taken was 1: 2.5. Soil electrical conductivity (EC) was measured using the Wensar Multiparameter water quality meter (Rhoades 1982). The soil to distilled water ratio taken was 1: 2.5. Soil organic carbon (SOC) was calculated using the modified Walkley Black titration method (Walkley and Black 1947). Percent of soil organic matter (SOM) was obtained by multiplying percent soil organic carbon by a factor of 1.724 following the assumption that organic matter is composed of 58% carbon. Soil total nitrogen as calculated using Kjeldahl method (Kirk 1950) (digestion, distillation, and titrimetric analysis). Soil C: N ratio was calculated using following formula:

$$\frac{\text{Soil organic carbon (\%)}}{\text{Soil total nitrogen (\%)}} \qquad (3)$$

The SOC and soil TN stocks (Mg ha^{-1}) were calculated as follows:

$$\text{SOC stock} = \text{SOC x BD x D x } 1 - \text{G} \quad (4)$$

$$\text{Soil TN stock} = \text{TN x BD x D x } 1 - \text{G} \quad (5)$$

In equation (4) and (5), where SOC is soil organic carbon concentration (%), TN is the soil total nitrogen concentration (%), D is the sampling depth (cm), BD is the bulk density (g cm^{-3}) and G refers to the gravel content (%).

Data analysis

Quantitative parameters such as percentage of frequency, density and abundance of each herbaceous species present in quadrats were recorded and analyzed as per the methods of Curtis and McIntosh (1950). The importance value index of species was calculated by summing the three relative values, viz., relative frequency, relative density and relative dominance of the species. The following formula were used:

$$\text{Relative Abundance (\%)} = \frac{\text{Abundance of individual species}}{\text{Total abundance of all species}} \text{x } 100\% \quad (6)$$

$$\text{Relative Density (\%)} = \frac{\text{Density of individual species}}{\text{Total density of all species}} \text{x } 100\% \quad (7)$$

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of individual species}}{\text{Total frequency of all species}} \text{x } 100\% \quad (8)$$

$$\text{IVI= Relative Abundance + Relative Density + Relative Frequency} \quad (9)$$

The ratio of abundance to frequency (A/F) was worked out to interpret the distribution pattern of species (Whitford 1949; Curtis & Cottam 1956), Accordingly, the value for regular dispersion is < 0.025, random - 0.025 to 0.05 and contagious - >0.05. The species richness was calculated using Menhinick Index (Menhinick 1964) and Margalef Index (Margalef 1958). The species diversity was computed by using the Shannon-Wiener Diversity Index (Shannon-Wiener 1949) and Simpson's Index of diversity (Simpson 1949). Species evenness was calculated using Shannon Equitability index (E_H)/ Pielou's Evenness Index (Pielou 1966). The formula used were as follows:

$$\text{Menhinick Index (R1)} = \frac{\text{S}}{\sqrt{\text{N}}} \quad (10)$$

$$\text{Margalef Index (R2)} = \frac{\text{S} - 1}{\ln N} \quad (11)$$

$$\text{Shannon Wiener Diversity Index (H')} = -\sum_{i=1}^{s} pi \ln pi \quad (12)$$

$$\text{Simpson Diversity Index (D)} = 1 - \sum_{i=1}^{s} (pi)^2 \quad (13)$$

$$\text{Pielou's Evenness Index (J)} = \frac{\text{H}'}{\ln \text{S}} \quad (14)$$

In the above equations (7-11), pi or (ni/N) = proportion of individuals belonging to species 'i' where ni is number of individuals of species 'i', N is the total number of individuals in the plot, S = total number of species in the plot.

The soil texture was computed using Gradistat 8.0. Descriptive statistics were performed using R studio and MS Excel (2013) analytical software and expressed as the mean value± standard error. One-way analysis of variance (ANOVA) and Tukey's post hoc test was performed to test the within and between significant differences of the different soil variables at $p<0.05$. Pearson correlation coefficient was calculated between biodiversity indices, biomass, and soil physicochemical properties of the open canopy and under canopy sites using R studio software. Redundancy analysis (RDA) (by Vegan package in R) was used to examine changes in herbaceous species biomass about open and under canopy sites.

Results

Vegetation characteristics

A total of 19 herb species were recorded from the study area. 11 were perennial and 8 were annual herbs. Grasses (11) were more in number compared to forbs (8). Grasses were higher in canopy gaps (9) than in under canopy (4) while forbs were higher in under canopy (7) than canopy gaps (6). Out of 6 families recorded for the representative species, *Poaceae* (9 species) was observed to be dominant at all study sites followed by *Amaranthaceae*, *Acanthaceae*, and *Malvaceae* (2 species). Details of herb species attributes are given in Table 1.

Table 1
Herbs species and their attributes encountered in the study area

S.No	Species	Family	Type	Life cycle	Physiology	Growth Form	Plant height (cm)	Leaf shape	Phyllotaxy	Leaf dimensions (L x B)	Type of system
1.	*Achyranthes aspera* L.	*Amaranthaceae*	Forb	Perennial	C_3	Erect	Up to 200	Elliptic-obovate	opposite-decussate	10 cm x 8 cm	Tap
2.	*Ageratum houstonianum* Mill.	*Asteraceae*	Forb	Annual	C_3	Bushy	30–100	ovate to triangular	opposite	2–7 cm x 1.5-6 cm	Fibrous
3.	*Arundinella pumila* (Hochst. ex A. Rich.) Steud.	*Poaceae*	Grass	Annual	C_4	Erect	15–30	lanceolate	alternate	3–15 cm x 6–18 mm	Fibrous
4.	*Brachiara ramosa* (L.) Stapf	*Poaceae*	Grass	Annual	C_4	Erect to prostrate	30–60	linear	alternate	2–25 cm x 4–14 mm	Fibrous rooting lower st nodes.
5.	*Cenchrus ciliaris* L.	*Poaceae*	Grass	Perennial	C_4	Erect, tufted tussock-forming	10–150	linear	alternate	3–30 cm x 4–10 mm	Fibrous rhizoma
6.	*Chloris barbata* Sw.	*Poaceae*	Grass	Annual	C_4	Erect, tufted	30–100	linear-lanceolate	alternate	10–20 cm x 2–3 mm	Fibrous rooting lower st nodes.
7.	*Chrysopogon sp.*	*Poaceae*	Grass	Perennial	C_4	Erect, clumping, tussock	100–150	linear	alternate	30–90 cm x 0.5 -1 cm	Fibrous buried r
8.	*Cynodon dactylon* (L.) Pers.	*Poaceae*	Grass	Perennial	C_4	Erect to prostrate	15–25	linear-lanceolate	alternate	1–10 cm x 0.1–0.5 cm	Fibrous stolonif rhizoma
9.	*Dactyloctenium aegyptium* (L.) Willd.	*Poaceae*	Grass	Annual	C_4	Erect, tufted	Up to 50	linear	alternate	3–25 cm x 3–15 mm	Fibrous rooting lower st nodes.
10.	*Dipteracanthus prostratus* (Poir.) Nees	*Acanthaceae*	Forb	Perennial	C_3	Prostrate	up to 50	ovate	opposite	6 cm x 4 cm	Adventi roots, st trails ar roots at nodes
11.	*Elytraria acaulis* (L.f.) Lindau	*Acanthaceae*	Forb	Perennial	C_3	Rosette	up to 30	obovate	rosette	5–26 cm x 1-7.5 cm	Fibrous
12.	*Eragrostis ciliaris* (L.) R. Br.	*Poaceae*	Grass	Perennial	C_4	Erect, tufted, clumping	5–60	linear	alternate	2–12 cm x 1–5 mm	Fibrous
13.	*Heteropogon contortus* (L.) Beauv. Ex Roem. & Schult.)	*Poaceae*	Grass	Perennial	C_4	Erect, tufted, tussock	50–150	linear-lanceolate	alternate	3–30 cm x 2–8 mm	Fibrous rhizoma
14.	*Hibiscus lobatus* (Murray) Kuntze.	*Malvaceae*	Forb	Annual	C_3	Erect	50–130	sub orbicular to ovate	alternate	2–12 cm x 1·5–10 cm	Tap
15.	*Lathyrus palustris* L	*Fabaceae*	Forb	Perennial	C_3	Climber	20–120	pinnate; leaflets linear to ovate	alternate	3-8.5 cm x 0.7–2.3 cm	Tap, rhizoma
16.	*Oplismenus burmannii* (Retz.) P. Beauv.	*Poaceae*	Grass	Annual	C_3	Prostrate	20–50	elliptic or elliptic-lanceolate	alternate	1–5 cm x 0.6–1.2 cm	Adventi roots, st trails ar roots at nodes
17.	*Pupalia lappacea* (L.) Juss	*Amaranthaceae*	Forb	Perennial	C_3	Erect or prostrate	60–90	ovate-elliptic to oblong or round	opposite	2–12 cm x 1–6 cm	Tap

S.No	Species	Family	Type	Life cycle	Physiology	Growth Form	Plant height (cm)	Leaf shape	Phyllotaxy	Leaf dimensions (L x B)	Type of system
18.	*Setaria verticillata* (L.) P.Beauv.	*Poaceae*	Grass	Annual	C_4	Erect, tufted	30–100	linear	alternate	30 cm x 1-1.5 cm	Adventi stem ro at lowe nodes
19.	*Sida* sp.	*Malvaceae*	Forb	Perennial	C_3	Erect	Up to 60	ovate	alternate	1.5–5.5 cm x 1-3.5 cm	Tap

Oplismenus burmannii, *Setaria verticillata*, *Dipteracanthus prostatus*, and *Ageratum houstonianum* was recorded only in the under canopy region. *Cenchrus ciliaris*, *Chrysopogon sp.*, *Arundinella pumila*, *Dactyloctenium aegyptium*, *Heteropogon contortus*, *Chloris barbata*, *Eragrostis ciliaris*, and *Lathyrus palustris* was recorded only in canopy gaps. *Cynodon dactylon*, *Brachiara ramosa*, *Hibiscus lobatus*, *Elytraria acaulis*, *Pupalia lappacea*, *Achyranthes aspera*, and *Sida sp.* was recorded in both canopy gaps and under canopy regions.

The species found in under canopy areas had shorter plant height (less than 1 m). The growth form was mainly bushy/prostrate/rosette. However the species in canopy gaps were mostly taller (more than 1 m) and had erect growth form showing clumping/tufted growth. The species in under canopy had mostly shorter and broader leaves while those in canopy gaps had longer and narrower leaves. Species in both the regions showed vegetative growth through stolon and rhizome. In the under canopy *Oplismenus burmannii and Dipteracanthus prostatus* possessed trailing stem rooting at the nodes. In the canopy gaps, *Cenchrus ciliaris* and *Heteropogon contortus* propagated through rhizomes. The two-way cluster analysis revealed distinct clustering pattern due to the influence of the canopy which clearly indicates that some species have distant clustering, while some have smaller clustering patterns (Fig. 2). A smaller cluster was formed between *Eragrostis ciliaris* and *Sida sp.*, *Lathyrus palustris*, and *Chloris barbata*.

Relative frequency (RF%), relative density (RD%), relative abundance (RA%), A/F ratios, and IVI of different species is compared in Table 2. *Oplismenus burmannii* recorded significantly high relative density among all species in under canopy regions (PSR: 71.37%; PRV: 97.06%). In canopy gaps, at PSR, *Eragrostis ciliaris* (23.52%) and *Cenchrus ciliaris* (22.86%) and PRV, *Achyranthes aspera* (25.78%) and *Chrysopogon sp.* (24.69%) recorded higher relative density. *Oplismenus burmanni* dominated in PSR (138.0 IVI) and PVR (230.5 IVI) under canopy sites, *Eragrostis ciliaris* (53.1 IVI) and *Achyranthes aspera* (56.15 IVI) dominated in PSR and PVR canopy gaps respectively. Another important species in under canopy area was *Dipteracanthes prostatus* having higher relative frequency (PSR: 16.12%, PRV: 31.81%). A/F ratio for all species was recorded > 0.05, thus all species showed contagious distribution.

Table 2
Phytosociological attributes of herbs species in the canopy gaps and under canopy regions of study sites.

	PSR UNDERCANOPY					PRV UNDERCANOPY					PSR CANOPY GAPS					PR
Species	RF (%)	RD (%)	RA (%)	A/F	IVI	RF (%)	RD (%)	RA (%)	A/F	IVI	RF (%)	RD (%)	RA (%)	A/F	IVI	RF (%)
Achyranthes aspera	12.9	0.89	0.79	0.175	14.59	9.09	0.08	0.38	0.2	9.56	11.76	5.51	3.39	0.83	20.67	17.8
Ageratum houstonianum	3.22	4.23	14.99	13.2	22.45	-	-	-	-	-	-	-	-	-	-	-
Arundinella pumila	-	-	-	-	-	-	-	-	-	-	9.8	11.54	8.52	2.51	29.87	3.5
Brachiara ramosa	6.45	0.38	0.68	0.3	7.51	-	-	-	-	-	5.88	6.98	8.6	4.22	21.46	7.14
Cenchrus ciliaris	-	-	-	-	-	-	-	-	-	-	13.72	22.86	12.06	2.53	48.66	10.7
Chloris barbata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5
Chrysopogon sp.	-	-	-	-	-	-	-	-	-	-	1.96	6.98	25.8	38	34.74	17.8
Cynodon dactylon	6.45	5.26	9.31	4.1	21.02						11.76	5.88	3.62	0.88	21.26	10.7
Dactyloctenium aegyptium	-	-	-	-	-	-	-	-	-	-	7.84	4.11	3.8	1.4	15.76	3.5
Dipteracanthus prostratus	16.12	4.1	2.9	0.512	23.14	31.81	1.69	2.07	0.31	35.58	-	-	-	-	-	-
Elytraria acaulis	12.9	1.15	1.02	0.225	15.08	-	-	-	-	-	1.96	0.07	0.27	0.4	2.305	3.5
Eragrostis ciliaris	-	-	-	-	-	-	-	-	-	-	7.84	23.52	21.72	8	53.1	-
Heteropogon contortus	-	-	-	-	-	-	-	-	-	-	7.84	10.29	9.5	3.5	27.64	7.14
Hibiscus lobatus	6.45	2.18	3.86	1.7	12.49	9.09	0.8	3.43	1.8	13.32	9.8	1.1	0.81	0.24	11.72	7.14
Lathyrus palustris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5
Oplismenus burmannii	16.12	71.37	50.52	8.896	138.0	40.9	97.06	92.58	10.7	230.5	-	-	-	-	-	-
Pupalia lappacea	6.45	3.59	6.36	2.8	16.4	-	-	-	-	-	5.88	0.29	0.36	0.17	6.53	3.5
Setaria verticillata	9.67	6.16	7.26	2.133	23.1	9.09	0.35	1.52	0.8	10.97	-	-	-	-	-	-
Sida sp.	3.22	0.64	2.27	2	6.13	-	-	-	-	-	3.92	0.8	1.49	1.1	6.22	-

RF = Relative frequency; RD = Relative Density; RA = Relative Abundance; A/F = Abundance Frequency Ratio; IVI = Importance Value Index

Species diversity

In general, canopy gaps showed higher species richness and evenness and thus had greater species diversity compared to under canopy sites (Table 3). Menhinick Index of species diversity was the lowest in PRV under the canopy (0.05) and the highest in PRV canopy gaps (0.24) while Margalef Index ranged from 0.44 to 1.50. The Shannon-Wiener diversity index (H') ranged from 0.16 to 2.10, it was the lowest in PRV under the canopy (0.16). Simpson index (D_2) ranged from 0.06 to 0.85 and was the highest in canopy gaps. The species evenness calculated by Shannon Equitability index (E_H), ranged from 0.1 to 0.82. PSR canopy gaps and PRV under canopy recorded highest and least species evenness respectively among all sites.

Table 3
Diversity indices of herbs species in the open canopy and under canopy regions of study sites.

Diversity indices	PSR UNDER CANOPY	PRV UNDER CANOPY	PSR CANOPY GAPS	PRV CANOPY GAPS
Menhinick Index	0.2	0.05	0.18	0.24
Margalef Index	1.24	0.44	1.40	1.50
Shannon Wiener Index (H')	1.18	0.16	2.10	2.00
Simpson Index (D_2)	0.48	0.06	0.85	0.85
Shannon Equitability Index (E_H)	0.49	0.1	0.82	0.78

Biomass

The sum of the total biomass of all species was higher in canopy gaps than under the canopy area (Table 4). At PSR canopy gaps, the total biomass of all species was 924.27 g m^{-2} (aboveground biomass 607.48 g $m^{-2}$and belowground biomass 316.79 g m^{-2}), while at PRV canopy gaps, it was 701.03 g m^{-2} (aboveground biomass 506.33 g m^{-2} and belowground biomass 194.69 g m^{-2}). In the under-canopy area, the total biomass was significantly lower. At PSR under the canopy, it was 30.64 g m^{-2} (aboveground biomass 24.74 g m^{-2} and belowground biomass 5.9 g m^{-2}), while at PRV under the canopy it was 73.06 g m^{-2} (aboveground biomass 62.17 g m^{-2} and belowground biomass 10.89 g m^{-2}). The highest biomass at PSR under the canopy was recorded for *Cynodon dactylon* (9.6 gm^{-2}) while at PRV under canopy was recorded for *Oplismenus burmanni* (52.21 gm^{-2}). The highest biomass in canopy gaps was recorded by *Cenchrus ciliaris* (597.97 gm^{-2}) at PSR and *Chrysopogon sp.* (391.2 gm^{-2}) at PRV. The grass species contributed the maximum to the total herbaceous biomass at all sites. The grasses having the highest biomass at canopy gaps had relatively low AGB/BGB (*Cenchrus ciliaris*: PSR-1.14 PRV-1.72; *Chrysopogon sp.*: PSR-1.18 PRV-2.38) compared to other species.

Table 4
List of herbs species encountered in canopy gaps and under canopy with their AGB, BGB, and TB, AGB / BGB ratio in study sites.

	PSR UNDERCANOPY				PRV UNDERCANOPY				PSR CANOPY GAPS				PRV CANOPY GAPS		
Species	AGB	BGB	TB	AGB/BGB	AGB	BGB	TB	AGB/BGB	AGB	BGB	TB	AGB/BGB	AGB	BGB	T
Achyranthes aspera	0.92	0.37	1.30	2.48	0.28	0.03	0.31	10.93	33.15	2.23	35.39	14.80	35.85	2.66	3
Ageratum houstonianum	3.09	1.38	4.47	2.23	-	-	-	-	-	-	-	-	-	-	-
Arundinella pumila	-	-	-	-	-	-	-	-	3.34	0.55	3.90	6.01	3.29	0.49	3
Brachiara ramosa	0.05	0.01	0.06	5.80	-	-	-	-	0.64	0.11	0.75	5.69	0.78	0.14	0
Cenchrus ciliaris	-	-	-	-	-	-	-	-	384.8	213.1	597.97	1.80	113.36	65.88	1
Chloris barbata	-	-	-	-	-	-	-	-	-	-	-	-	6.02	0.36	6
Chrysopogon sp.	-	-	-	-	-	-	-	-	103.4	90.44	193.84	1.14	275.32	115.88	3
Cynodon dactylon	7.64	1.96	9.60	3.90	-	-	-	-	8.73	0.62	9.36	13.88	3.40	0.25	3
Dactyloctenium aegyptium	-	-	-	-	-	-	-	-	10.80	0.53	11.34	20.14	1.13	0.15	1
Dipteracanthus prostratus	2.88	0.28	3.16	10.32	14.3	2.28	16.6	6.28	0.00	-	-	-	-	-	-
Elytraria acaulis	2.01	0.33	2.35	6.01	-	-	-	-	0.80	0.20	1.00	4.00	0.54	0.18	0
Eragrostis ciliaris	-	-	-	-	-	-	-	-	5.48	0.17	5.65	31.89	-	-	-
Heteropogon contortus	-	-	-	-	-	-	-	-	49.07	7.47	56.55	6.56	32.77	5.65	3
Hibiscus lobatus	0.73	0.09	0.82	8.37	2.13	0.22	2.35	9.58	1.50	0.22	1.72	6.78	28.65	2.40	3
Lathyrus palustris	-	-	-	-	-	-	-	-	-	-	-	-	0.51	0.15	0
Oplismenus burmannii	3.51	0.64	4.15	5.46	44.0	8.16	52.2	5.39	-	-	-	-	-	-	-
Pupalia lappacea	0.46	0.07	0.53	6.53	-	-	-	-	4.26	0.88	5.14	4.84	4.72	0.50	5
Setaria verticillata	3.34	0.72	4.06	4.63	1.38	0.20	1.58	6.92	-	-	-	-	-	-	-
Sida sp.	0.11	0.04	0.16	2.47	-	-	-	-	1.42	0.18	1.60	7.92	-	-	-

AGB = Above Ground Biomass; BGB = Below Ground Biomass; TB = Total Biomass.

According to Pearson correlation analyses, herbaceous AGB, BGB, and TB were positively correlated with the diversity indices (Menhenick Index, Shannon Weiner Index, Margalef, Simpson Index, and Shannon Equatibility Index) (Fig. 3). This indicates higher species diversity supported greater productivity.

Soil physico-chemical properties

Soil moisture was lower in canopy gaps as compared to under canopy while the bulk density showed the reverse trends (Fig. 4). Soil clay, silt, and sand content did not vary between canopy gaps and under canopy sites. Soil pH, soil EC, SOC, TN, SOM, SOC/TN, and soil carbon and nitrogen stock varied little both among and within sites (Fig. 5). The soil of under canopy regions had lower pH than canopy gaps of the same site, thus pH varied significantly ($p < 0.05$). The soil of under canopy regions had higher EC than canopy gaps at both sites. Also, under canopy sites had significantly ($p < 0.05$) higher SOC, TN, and SOM contents and soil carbon and nitrogen stock than canopy gaps. Soil SOC/TN ratio was higher in PSR under canopy sites. Thus soils of under canopy regions were acidic, had greater porosity and soil moisture, and were richer in organic matter and nutrients compared to canopy gaps. Pearson correlation analyses showed that SOC, TN, SOM contents, SOC stock and TN stock were positively correlated with each other (Fig. 3). However, SOC, TN, SOM contents, SOC stock and TN stock were negatively correlated with bulk density and soil pH and significantly correlated with soil moisture contents (Fig. 3). This indicates that greater soil organic matter retained more soil moisture, reduced pH, and increased the porosity of the soil. Redundancy analysis (RDA) confirmed the correlation between soil physicochemical properties and biomass (Fig. 6). RDA axes 1 and 2 shows 74.14 and 9.49% variation in composition respectively. RDA indicated that the biomass of most of the herbs species tended to be higher at the PSR and PRV canopy gaps and were negatively related to the soil

chemical properties (SOC, TN, SOM, SOC stock and TN stock). *Chloris barbata*, *Lathyrus palustris*, *Ageratum houstonianum*, *Chrysopogon sp.*, *Arundinella pumila* correlated with soil bulk density. As shown in Fig. 6, *Oplismenus burmannii* and *Dipteracanthus prostratus* showed positive relationship with soil chemical properties (SOC, TN, SOM, SOC stock and TN stock).

Discussions

Species composition and diversity

The species found in the present study belonged to either of the 6 families – *Poaceae*, *Malvaceae*, *Amaranthaceae*, *Asteraceae*, *Acanthaceae*, and *Fabaceae* which are among 10 dominant families in the region (Mishra et al., 2015b). The dominant family was *Poaceace* (grass family) which is the dominant family of herb species in Aravalli hills (Gaury and Devi, 2017). In the present study, herbaceous species composition and dominant species varied in canopy gaps and under the tree canopy. Under canopy was dominated by *Oplismenus-Dipteracanthus* community while canopy gap was dominated by *Cenchrus-Chrysopogon* community. Several other studies also reported differences in herbaceous communities in the and canopy gaps (Sagar et al., 2012; Singh et al., 2017).

In another study, clear harvesting of trees in oak–hornbeam forests changed the understory vegetation considerably as compared to intact tree stands (Tinya et. al., 2018). Similar to the present study, canopy gaps hosted a higher number of colonizing species with greater plant height in temperate fir-beech forests (Kermavnar et. al., 2019). Increasing light availability followed by warming led to establishment of taller herb community in temperate deciduous forest (Blondeel et. al., 2020). Plants that are shaded by similar sized neighbors (as in the case of canopy gaps), produce longer internodes (resulting in increased plant height) and larger leaves to maximize light capture (Poorter et. al., 2019). According to Bonser and Geber 2005, erect growth forms are favored in low-light habitats and rosette or prostrate growth forms under high-light habitats. However present study showed reverse trend. In a study, erect species showed greater competitive ability (in terms of leaf number) than other growth forms (Fazlioglu et. al., 2016). In present study also, species having erect growth form dominated the study area. Also, higher number of C_4 plants were present in canopy gaps while higher number of C_3 plants under the canopy in our study. C_4 photosynthesis evolved as an adaptation to high light intensities, high temperatures and dryness. Therefore, C_4 plants dominate grassland and biomass production in tropical and subtropical regions (Edwards et al., 2010).

Understorey vegetation serves as a good indicator of the ecological condition of a system (Schmidt, 2005; Mataji et. al. 2010). Most of the species (*Achyranthes aspera*, *Brachiara ramosa*, *Cynodon dactylon*, *Cenchrus ciliaris*, *Chrysopogon sp.*, *Dactyloctenium aegyptium*, *Dipteracanthus prostatus*, *Eragrostis ciliaris*, *Sida sp.* and *Setaria verticillata*) found in the present study are species of disturbed areas such as roadsides, agricultural fields and wastelands (Mishra et al. 2015b) and are ruderals or weeds. *Chloris barbata* and *Sida sp.* are non-native species (Mishra et. al., 2015a). Presence of such species in the study area suggests it is a disturbed site, however the extent of disturbance was not evaluated. Across the sites, all species showed contagious pattern of the distribution. In natural conditions, contagious distribution is the most common type of distribution and is performed due to small but significant variations in environmental conditions (Odum, 1971). In our study, several species reproduced through vegetative propagation through stolon, rhizomes and adventitious roots. Many species had tufted or clumped growth forms. The dominance of contagious distribution may be due to the fact that majority of grass species reproduce vegetatively in addition to their sexual reproduction (Shameem et al., 2017).

Species diversity was higher in canopy gaps than at under the canopy area. Singh et al., 2017 also reported that the distribution and number of unique species were higher in grassland vegetation as compared to under forest in dry tropical forests of India. Studies in a temperate deciduous forest by Vockenhuber et al., (2011) also showed a negative response of herbaceous species richness to increasing canopy cover. The herb density and species richness were higher in the open canopy of sal forest of central Himalayas, India due to maximum space, less canopy cover, low density of trees and proper sunlight. Herbaceous density was lower in sal mixed canopy forest due to the closed canopy, higher tree density and presence of more number of broad-leaved associated tree species (*Tectonis grandis*, *Mallotus philippensis*, and *Terminalia sp.*) interrupting light to reach the ground vegetation (Adhikari et al., 2018). Some studies suggested that the decrease in species richness and diversity under the canopy is due to an increase in soil nitrogen input which leads to the loss of many nitrogen-efficient species and brings about the dominance of few high nitrogen-requiring species (Gilliam 2006). Species richness and simpson diversity index increased with increasing gap area and increasing light availability in beech stands (Vajari et al., 2012). In a natural disturbance-based silvicultural system, harvest gaps conserved understory plant diversity by promoting moderate disturbance. However, it also led to introduction of invasive plant species (Bolton and Amato 2019). Rainforest trees invasion in open forests led to decline in understory plant diversity and cover in open forests in Australia (Baker et al., 2020). Light availability was positively correlated with understory plant species richness and with understory cover in temperate forest also (Dormann et. al., 2020).

Biomass

The total herbaceous biomass in canopy gaps ranged from 700–900 gm^{-2} while in under canopy area it ranged from 30–70 gm^{-2}. Varshney (1972) recorded maximum shoot biomass 771 gm^{-2} and a minimum of 9 gm^{-2} for the grasslands of the region. In the semi-arid grasslands of Khirasara, the maximum shoot biomass recorded was 201 gm^{-2} (Singh and Krishnamurthy, 1981). The semi-arid region of India has *Cenchrus-Dicanthium* dominated grasslands (Dabadghao & Shankarnarayan, 1973; Chandran, 2015). In the present study also, *Cenchrus ciliaris* constituted major proportion of herbaceous community biomass in canopy gaps of the semi-arid forests.

Singh et al. 2017 also reported higher herbaceous biomass in open grasslands compared to under the canopy of the trees. In another study, moist dense forest canopies showed negative effect on herbaceous biomass (Shirima et. al., 2015). Similar trend was seen in Mediterranean dehesas (López-Carrasco et. al., 2015). Canopy plants absorb a large proportion of the available irradiance, water and nutrients, so there is always likely to be competition for resources between canopy and understorey plants (Valladares et al., 2016). However, other studies (Das et al., 2008; Sagar et al., 2012) reported positive effects of tree canopy on herbaceous diversity and production in dry tropical forests of Northern India.

Herbaceous peak biomass is intimately related to annual production and can be used as a substitute for the measurement of productivity (Sagar et al., 2012). In the present study positive correlation was found between species diversity and biomass (under canopy areas had lower species diversity and biomass while reverse was seen in canopy gaps). A linear relationship between productivity (peak biomass) and diversity was also found in several other studies (Abrams 1995; Bai et al., 2007; Sagar et al., 2012; Singh et al., 2017). Our study supported the diversity–stability hypothesis of Elton (1958) i.e. higher species diversity supports greater productivity in the ecosystem. However, reverse trend was seen in a study of mountain forests along the elevation gradient. There, increase in the diversity, richness, and species evenness of herbaceous plants resulted in a decrease in the plant dry biomass (Shahriari et. al., 2019).

Soil Physico-chemical Properties

In this study, the soil moisture content was higher in under canopy region and ranged between 8–20% while in canopy gaps it ranged from 3–10%. Savanna trees and shrubs may reduce the sub-canopy solar radiation by 45 to 60%, which may lower the soil temperature and evapotranspiration, which may subsequently increase the soil moisture content (Vetaas 1992). Studies have shown that soils developing under the tree canopy have a greater water-holding capacity and a macroporosity favorable to infiltration and redistribution of soil water (Joffre and Rambal 1993). Direct solar radiation, due to canopy opening, increases evaporative demand and reduction in soil moisture (Joshi et al., 2001; Pausas and Austin, 2001; Sagar et al., 2012; Shirima et al., 2015; Singh et al., 2017). Lower water holding capacity and soil moisture could be due to synergistic events of direct solar radiation, canopy gaps and soil structure mediated by the local anthropogenic disturbances on the sites (Singh et al., 2017). In this study, the soil bulk density was slightly higher in canopy gaps. This is due to soils beneath the canopy are more fertile and less compact than those in the canopy gaps (Gómez-Aparicio et al., 2005).

As in the present study, Joshi et al., 2001; Das and Chaturvedi 2008; Sagar et al., 2012; Singh et al., 2017; Desta et al., 2018; Amolikondori et. al., 2020 also reported higher soil moisture, soil organic carbon, soil nitrogen, and lower soil pH in under canopy regions compared to canopy gaps. This may be due to greater litter inputs, tree roots turnover and dust accumulation on the canopy which gets transported to the soil by through-fall and/or stem-flow. In another study of dry lands in Ethopia, effect of *Acacia saligna* canopy on soil physic-chemical properties was seen. Soil bulk density increased as the distance from the tree trunk increased. However, soil total nitrogen, soil organic carbon, moisture content, silt and clay percentages and soil electrical conductivity were greater under the canopy compared to outside the canopy (Gebretsion et. al., 2019). In the present study, there was a negative correlation of herbaceous biomass with soil physicochemical properties. Singh et al., 2017, found an increase in herbaceous biomass with a decrease in soil water and nutrients in grasslands. This may be due to the higher efficiency of C_4 grasses to photosynthesize in low moisture and nutrient conditions. However, in other studies (Das et al., 2008; Sagar et al., 2012) positive relation of soil moisture and nutrient availability with herbaceous diversity and productivity was seen.

Conclusion

Herbaceous species composition, diversity, biomass, and soil physicochemical properties showed significant variations in canopy gaps and under tree canopy sites of semi-arid forests. Canopy gaps and under canopy sites were dominated by different species. Species diversity and biomass were significantly higher in canopy gaps. C_4 plants (grasses) had a major contribution to species diversity and biomass of canopy gaps. A linear relationship occurred between species diversity and biomass. Canopy cover had positive effects on soil moisture and nutrients. However, soil chemical properties (SOC, TN, SOM, SOC stock, and TN stock) were negatively related to herbaceous species biomass. The increase in herbaceous diversity and biomass with reduced water and nutrient conditions in canopy gaps can be utilized for the management of forest under the present changing climate scenario where C sequestration can be enhanced with fewer inputs (Singh et al. 2017).

Abbreviations

AGB: Above ground biomass; A/F: Abundance Frequency Ratio; ANOVA: Analysis of variance; BD: Bulk Density; BGB: Below Ground Biomass; CG: Canopy Gap; EC: Electrical Conductivity; IVI: Importance Value Index; PRV: Poorvanchal; PSR: ParthSarthi Rocks; RA: Relative Abundance; RD: Relative Density; RDA: Redundancy Analysis; RF: Relative Frequency; SOC: Soil Organic Carbon; SOM: Soil Organic Matter; TB: Total Biomass; TN: Total Nitrogen; UC: Under Canopy

Declarations

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Authors' contributions

SCG conceived the idea. SG and RKJ designed and conducted the field experiment and analyzed the data. SCG, SG, and RKJ wrote the manuscript and approved the final manuscript.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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All data generated or analyzed during this study are included in this published article.

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Figures

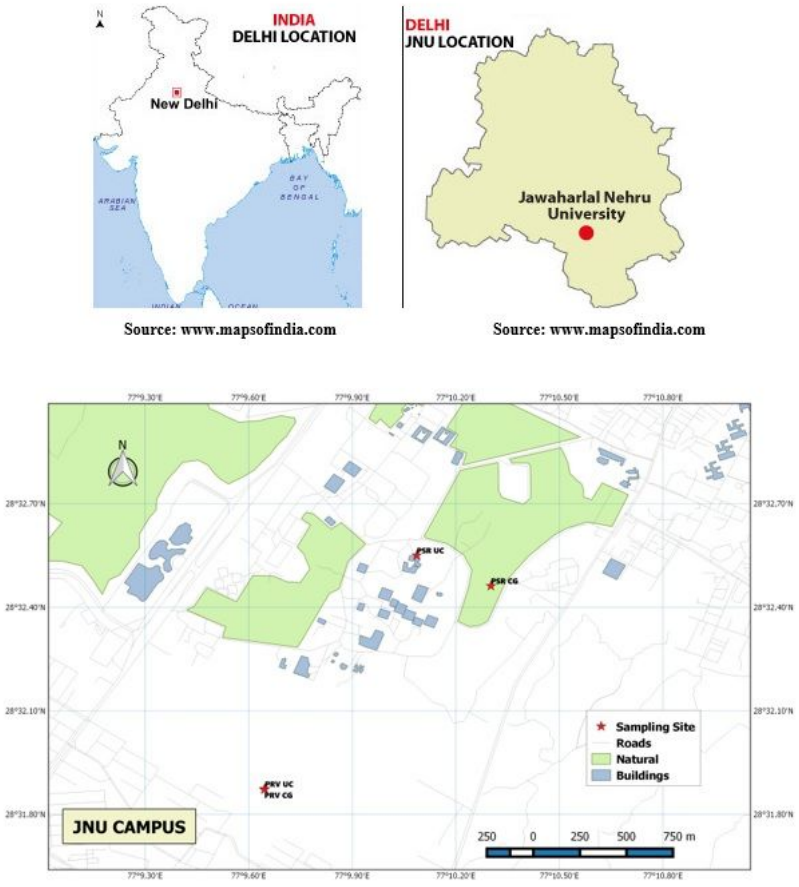

Figure 1

Map of study area (JNU=Jawaharlal Nehru University, New Delhi). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

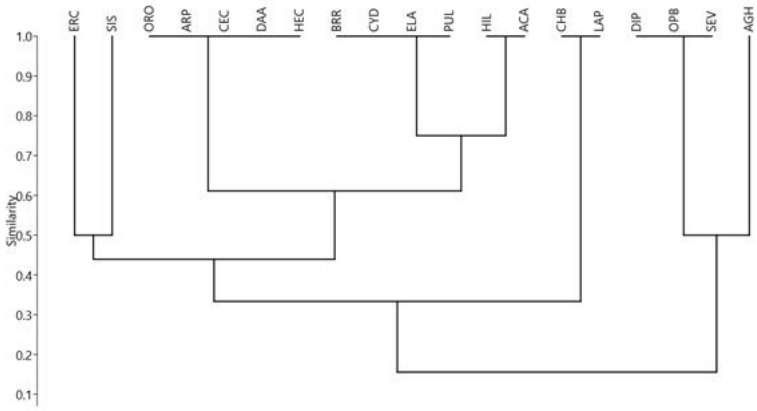

Figure 2

Clustering of herb species in open canopy and under canopy regions. Each code indicates the name of the species. (Achyranthes aspera =ACA, Ageratum houstonianum=AGH, Arundinella pumila =ARP, Brachiara ramose=BRR, Cenchrus ciliaris=CEC, Chloris barbata=CHB, Chrysopogon sp. =ORO, Cynodon dactylon=CYD., Dipteracanthus prostratus=DIP, Dactyloctenium aegyptium=DAA, Elytraria acaulis=ELA, Eragrostis ciliaris=ERC, Heteropogon contortus=HEC, Hibiscus lobatus=HIL, Lathyrus palustris=LAP, Oplismenus burmannii=OPB, Pupalia lappacea=PUL, Setaria verticillata=SEV, Sida sp.=SIS).

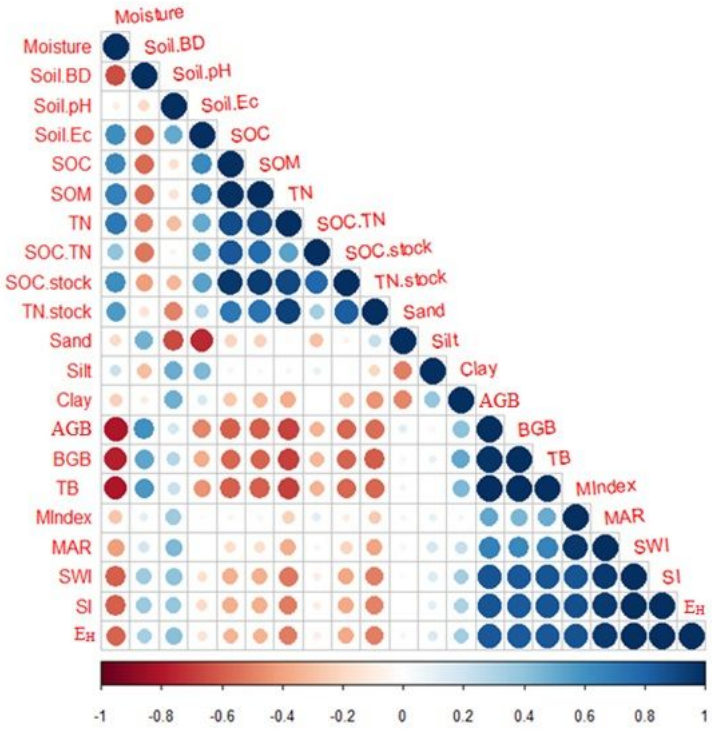

Figure 3

Pearson Correlation of diversity indices, herbaceous biomass, and soil physicochemical properties. BD=Bulk Density, SOM=Soil Organic Matter, SOC= Soil Organic Carbon, TN= Total Nitrogen, AGB=Above-Ground Biomass, BGB= Below-Ground Biomass, TB=Total Biomass, MINDEX= Menhinick Index, MAR= Margalef Index, SWI= Shannon Wiener Index (H'), SI= Simpson Index (D2), EH = Shannon Equitability Index /Pielou's evenness Index.

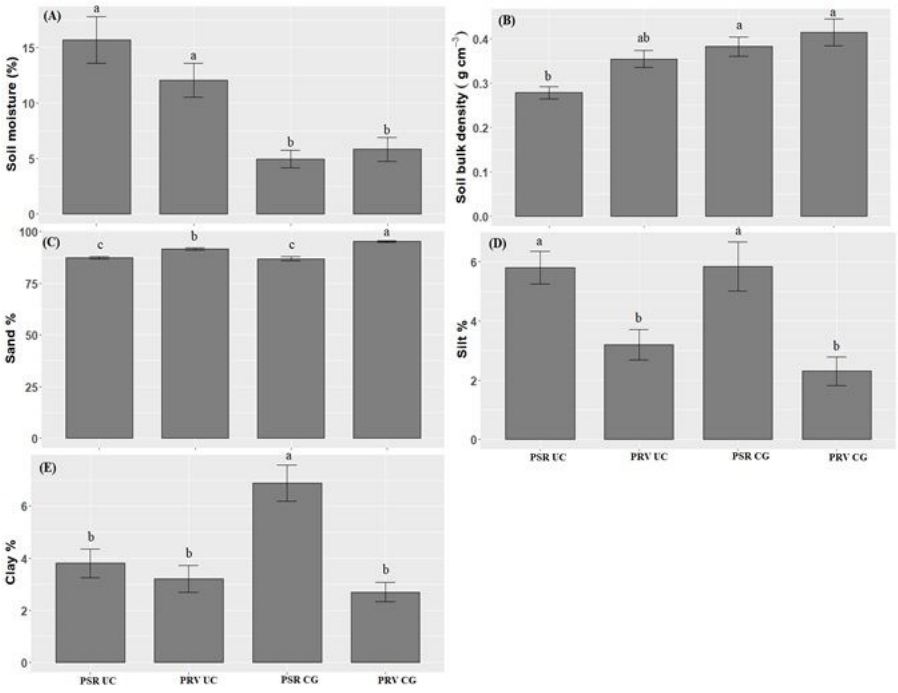

Figure 4

Soil physical properties at four sites of the study area. Different letters indicate significant differences among means after Tukey's test ($P \leq 0.05$). Error bars represent the standard error of the mean values.

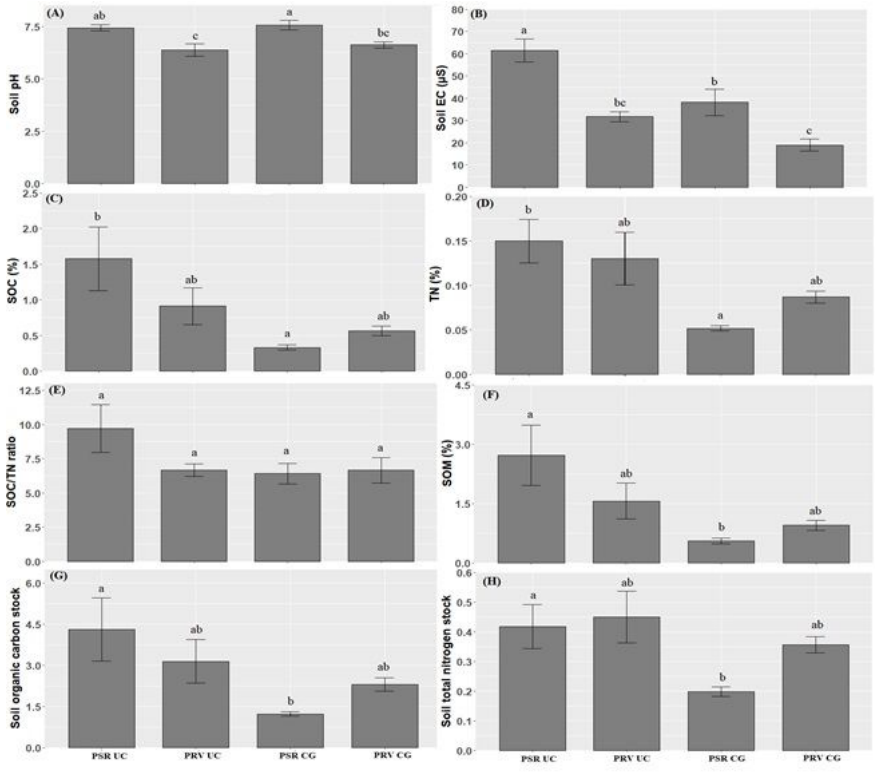

Figure 5

Soil physical properties at four sites of the study area. Different letters indicate significant differences among means after Tukey's test ($P \leq 0.05$). Error bars represent the standard error of the mean values.

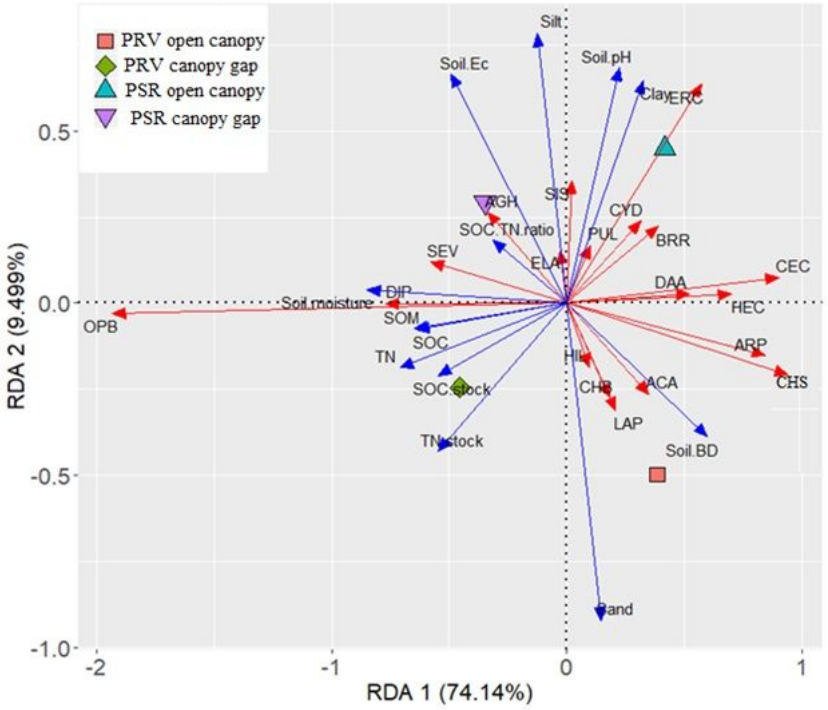

Figure 6

edundancy analysis (RDA) of association of herbs species biomass and soil properties in the canopy and under canopy sites. Each code indicates the name of the species. (Achyranthes aspera =ACA, Ageratum houstonianum=AGH, Arundinella pumila =ARP, Brachiara ramose=BRR, Cenchrus ciliaris=CEC, Chloris barbata=CHB, Chrysopogon sp. =CHS, Cynodon dactylon=CYD, Dipteracanthus prostrates=DIP, Dactyloctenium aegyptium=DAA, Elytraria acaulis=ELA, Eragrostis ciliaris=ERC, Heteropogon contortus=HEC, Hibiscus lobatus=HIL, Lathyrus palustris=LAP, Oplismenus burmannii=OPB, Pupalia lappacea=PUL, Setaria verticillata=SEV, Sida sp. =SIS).