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Functional Leaf Trait Variations in Seasonally Dry Tropical Forest Ecosystems at Gurgaon, Northern India

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ABSTRACT

This paper reports on a study of leaf phenology of trees, and variation in functional traits of leaves in tree and shrub species from three protected forests in the tropical dry deciduous forest region of Gurgaon district in northern India. The study area has a semiarid, tropical climate and the soil is old alluvium /sandy loam. The forests are dominated by *Ailanthus excelsa* and *Cassia fistula* (AE-CF) at Bhondsi, *Acacia leucophloea* and *Balanites aegyptiaca* (AL-BA) at Gawalpahari and *Anogeissus pendula* and *Acacia leucophloea* (AP-AL) at Raisina. The tree density was 492.5 to 642.5 trees ha^{-1} with a total basal area of 14.62 to 23.54 m^2 ha^{-1}. The leaf traits of trees and understorey shrubs varied in relation to microtopography and the vegetation composition of the three forests. There was significant effect of tree species on leaf area, leaf weight, specific leaf area and nitrogen content in the three forests ($P \leq 0.05$). The weight of leaves ranged from 0.050 to 2.701g across forest types. The specific leaf area (SLA, fresh leaf area/dry mass) was: 14.312 to 231.9 cm^2 g^{-1} in AE-CF forest; 13.431 to 181.65 cm^2 g^{-1} in AL-BA forest and 8.529 to 119.30 cm^2 g^{-1} in AP- AL forest. The variability in SLA was 1.88 to 3.12 fold among the tree species, and 2.11 to 5.51 fold among the shrub species. Leaf weight and leaf area in the case of both tree and shrub species were significantly correlated (R^2= 0.825 to 0.992). The variation in leaf attributes of the tree and understorey shrubs across forest types could be explained on the basis of differences in microtopography, soil water availability, and soil fertility. The variations in leaf phenology and leaf traits in the studied forests could play an important role in diversifying internal resource utilization and ecosystem functioning under highly seasonal climate.

Key Words: Trees; Shrubs; Leaf Phenology; Leaf Area; Leaf Weight; Specific Leaf Area (SLA).

INTRODUCTION

The tropical dry forests are under threat due to increasing anthropogenic activities in different regions of the world (Murphy and Lugo 1986, Gillespie et al. 2012, Sunderland et al. 2015). Nearly 30% of forests in mainland Southeast Asia are dry forests (Poffenberger 2000), whereas up to 60% of forests in India are comprised of tropical dry forests (Waeber et al. 2012). Tropical dry forests occur in climates exhibiting a marked seasonality in rainfall and drought period of four to eight months over the annual cycle (Olivares and Medina 1992). In the dry tropical forests, deciduousness is a phenological attribute enabling adaptation of trees to strongly seasonal climate conditions and drought (Singh and Kushwaha 2005). Leaf traits can be good predictors of the plant performance in tropical forests as they are closely associated with the growth and survival of the plants (Poorter and Bongers 2006, Powers and Tiffin 2010). The leaf traits determine plant behavior, and provide a useful link between processes ranging from leaf scales to the whole plant and the stand-level (Chabot and Hicks 1982, Schulze et al. 1994, Meir et al. 2002). Functional traits are directly or indirectly linked to population of plants and various ecosystem processes (Hillebrand and Matthiessen 2009). At the ecosystem level, specific leaf area (SLA) and leaf nitrogen content of component species have significant impact on primary productivity and nutrient cycling (Reich et al. 1992, Cornelissen et al. 1999, Aerts and Chapin 2000). Plant functional traits like specific leaf area, leaf nitrogen, and plant height regulate biomass production in forest ecosystems (Pakeman 2011, Laliberte and Tyliankis 2012).

Leaf dry mass and leaf surface area are considered to be important leaf attributes of the vascular plants in diverse types of ecosystems. Some studies have shown that plant growth forms are a convenient way of modeling the diversity of plant physiological functions into well recognized and manageable plant groups (Lavorel et al. 1997, Santiago and Wright 2007). Groupings of plant species on the basis of their functional traits can yield useful information on the relative contribution of each plant functional type to total plant biomass in an ecosystem (Hoorens et al. 2010).The global database of plant traits, known as TRY database has revealed variations within and between different functional groups of plants based on 52 groups of traits relating to the vegetative and regeneration stages in temperate, Mediterranean, and tropical moist forest ecosystems (Kattge et al. 2011). The leaf functional traits (LA, SLA, dry matter and water content) in ten co-existing tree species in a dry tropical forest in Costa Rica showed that the majority of variation in leaf traits could be explained by differences between species (Hulshof and Swenson 2010) . The leaf functional trait diversity in Vindhyan tropical dry deciduous forests in India has been analyzed by Chaturvedi et al. (2011a , 2014). The functional leaf and stem trait variations in 113 woody species of a seasonally dry tropical forest on the Caribbean coast of Colombia showed a close relationship between leaf and stem attributes (Castro and Newton 2015).

A greater understanding of the functional groups of plants is required for sustainable forest management and restoration in dry tropics. The objective of this study was to analyze interspecific leaf trait variations of the tree and shrub species in the seasonally dry tropical forest ecosystems varying in microtopogrphy and vegeta-tion composition in a semiarid region of northern India.

STUDY SITES

The protected dry deciduous forests selected for the study are located at Bhondsi, Gawalpahari and Raisina in Gurgaon district in northern India (27^0 27' to 28^0 32' N latitude and 76^0 39' to 77^0 32' E longitude; Figure 1). Altitude varies from 186 m to 437 m above mean sea level (msl)**.** The forest at Bhondsi is located on plain soil at an altitude of 186m above msl. The soil has an undulating topography at Gawalpahari whereas at Raisina, the forest is located on a low lying hill with an altitude of 437 m above msl**.** The climate of the study area is semi-arid and monsoonal with distinct winter, summer and rainy seasons. A major portion of rainfall is received during the rainy months from June to September. Salient features of the climatic conditions during the study period are shown in Figure 2..

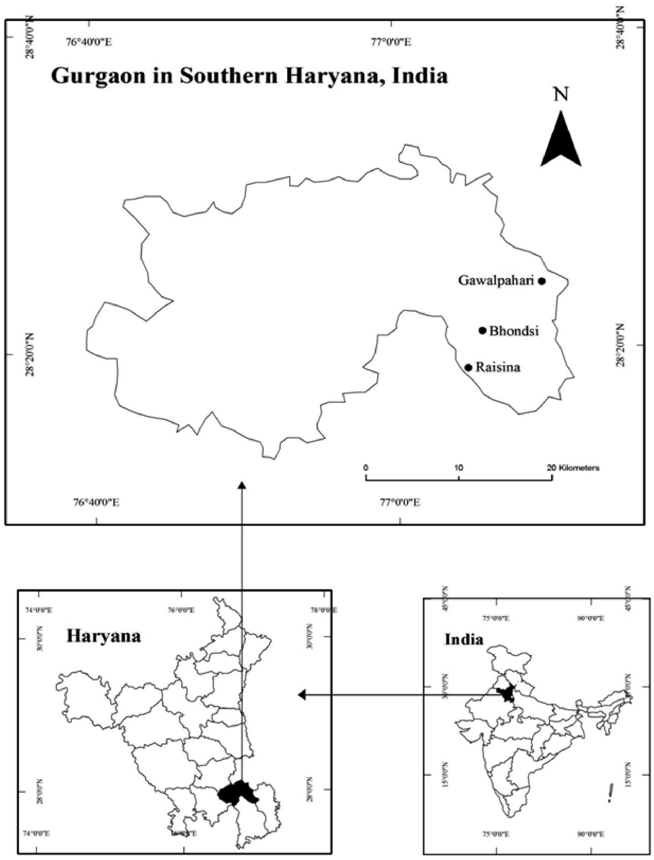

Figure 1. Location of the study sites in southern Haryana, India.

Vegetation composition and species diversity of the three forest ecosystems have been described by Singh et al. (2014). In brief, the dry deciduous forest (AE-CF forest) at Bhondsi is dominated by *Ailanthus excelsa* (IVI 38.71) and co-dominated by *Cassia fistula* (IVI 36.91), *Azadirachta indica* (IVI 29.84) and *Albizia lebbeck* (IVI 26.81). The Importance value index of other tree species in the forest varied from 3.97 to 24.35. The basal area of the predominant trees was in the order (m^2 ha^{-1})**:** 4.40 *Ailanthus excelsa,* >3.20 *Azadirachta indica,* >3.4 *Acacia nilotica,*>3.03 *Albizia lebbeck*. The density was 642.5 trees ha^{-1} and total basal area of trees was 23.54 m^2 ha^{-1}.

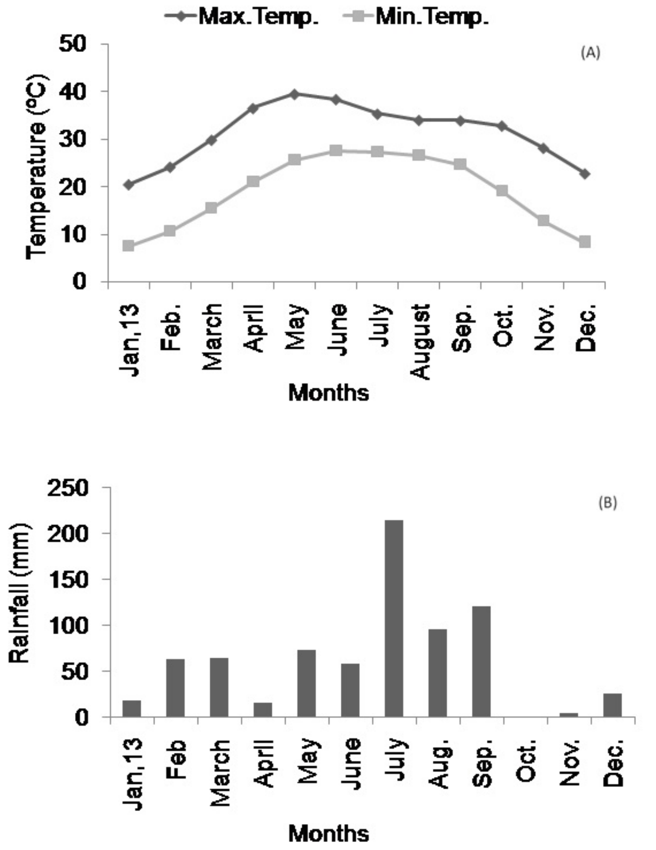

Figure 2. Monthly variations in (A) Temperature and (B) Rainfall of study area during January to December, 2013 (Source Haryana State Pollution Control Board).

The forest at Gawalpahari (AL-BA forest) is dominated by *Acacia leucophloea* (IVI= 50.27), and co-dominated by *Balanites aegyptiaca* (IVI= 41.66) and *Prosopis cineraria* (IVI= 41.47). The Importance value index of other tree species varied from 11.91 to 39.71. The basal area of trees ranged from 2.44 to 0.87 m^2 ha^{-1}. The stand density was 600 trees ha^{-1} and total basal area of trees was 15.52 m^2 ha^{-1}.

The forest at Raisina (AP-AL forest) is dominated by *Anogesisus pendula* (IVI= 89.20) and co-dominated by *Acacia leucophloea* (IVI =70.60) and *Prosopis juliflora* (IVI= 58.04). The basal area of trees (m^2 ha^{-1}) was**:** 4.60 *Anogeissus pendula,* >3.36 *Acacia leucophloea*, and >3.36 *Prosopis juliflora*. The density was 493 trees ha^{-1} and total basal area of trees was 14.62 m^2 ha^{-1}.

The Shannon index of diversity in the case of trees was higher for the dry deciduous forest at Bhondsi (H = 2.610) than that of the forest at Gawalpahari (H =2.233) and Raisina forest (H =1.601) (Singh et al. 2014). The concentration of dominance was in the order 0.221 Raisina >0.113 Gawalpahari forest> 0.082 forest at Bhondsi.

The soils at Bhondsi and Gawalpahari are old alluvium and sandy. At Raisina, the soil is sandy-loam and underlying rocks are quartzite, gritty quartzite, with thin intercalations of micaceous schist. The soil organic carbon concentration in the three forests varied from 0.21% to 0.31%; soil pH varied from 7.29 to 8.46. The bulk density of soil, based weight/ volume relationship as determined using the soil core method, ranged from 1.48 to 1.56 g cm^3 (Table 1). The soil water content in the three forests followed the order 8.24 to 24.5 % AE-CF forest Bhondsi > 7.53 to 22.34% AL-BA forest Gawalpahari > 6.23 to 20.56 % AP-AL forest Raisina.

METHODS

Analysis of Leaf Phenology of Trees

Phenological observations were made on 21 tree species relating to the duration of leaf fall, and the period of leaf flush from January to December, 2013. Leaf phenology was assessed on the basis of observations made in this study, the database of trees (Troup 1921) and the flora of

Table 1. Some physical and chemical soil characteristics at 0-15 cm soil depth in the tropical dry forests of Bhondsi, Gawalpahari and Raisina in Gurgaon. (Mean ± 1 SE)

Forest	Site	Soil pH (1:2)	Organic C (%)	Inorg. C (%)	Bulk density (g cm^{-3})	Soil water (%)
Ailanthus excelsa- Cassia fistula forest	Bhondsi	8.46 ±0.052	0.31 ±0.014	0.42 ±0.004	1.48 ±0.008	8.24-24.5
Acacia leucophloea- Balanites aegyptiaca forest	Gawalpahari	8.11 ±0.051	0.21 ±0.011	0.42 ±0.005	1.56 ±0.016	7.53-22.34
Anogeissus pendula- Acacia leucophloea forest	Raisina	7.29 ±0.049	0.29 ±0.011	0.43 ±0.006	1.50 ±0.010	5.33-20.56

Haryana (Jain et al. 2000). The deciduousness was estimated on the basis of the duration between leaf fall and new leaf flush (Troup 1921).

Leaf Sampling and Analysis

The leaves from robust, well-established plants of various tree species in the unshaded habitats were collected during the first week of August-September, 2013 in the three forests. Five trees, above 30-cm girth were marked in the experimental plots (20x20m) established for measuring the girth of trees. Three twigs were collected from the marked trees from the sun exposed branches and mid-canopy region with healthy and expanded leaves between 9:30 to 12:30 h (solar noon). Only completely developed leaves were sampled, without signs of herbivore damage and fungal infection. The leaves were dried with tissue paper to remove surface water and immediately weighed to determine their fresh weight. Leaf area was then measured using the, "millimeter graph paper method" following Pandey and Singh (2011). Also, we compared the millimeter graph paper method with leaf area meter (Leaf Area Meter 211, Systronics Ltd) and found them to be highly comparable. The graph paper method is convenient and cost-effective under field conditions. Leaf trait analysis followed the protocols for standardized trait measurements (Cornelissen et al. 2003). It may be mentioned that leaf area of individual pinna of the bipinnately compound leaf in the case of *Acacia leucophloea Acacia senegal, Leucaena leucocephala, Prosopis cineraria* , *Prosopis juliflora* was measured using the leaf area meter (Leaf Area Meter 211, Systronics Ltd) after transporting the twig samples in polyethylene bags with moist tissue paper to the field station at each site.

The leaves of seven shrub species including *Adhatoda vasica* Nees., *Calotropis procera* (Ait.) R. Br., *Capparis sepiaria* L., *Carissa spinarum* L., *Lantana camara* L., *Lycium europaeum* L., *Maytenus emarginata* Ding Hou were sampled during August-September 2013. Five stems from the marked shrubs with healthy and completely developed leaves were collected between 9:30 to 12:30 h (solar noon). From each stem two leaves were sampled and their areas were measured using the graph paper method; weighed under field conditions to determine their fresh weight.

The leaves were collected from the field in the individual marked paper bags for each species. The leaves were oven dried at 60^0C for 72 hr to obtain the dry mass with a precision electronic balance, to the nearest 0.001g. The SLA was calculated as the ratio of leaf area (cm^2) to leaf dry weight (g). For each compound leaf, leaf area was determined for all the leaflets.

Analysis of Nitrogen Concentration in Plants

Oven dried plant samples were powdered in a Wiley mill equipped with 2mm sieve. Total nitrogen concentration in the leaves of trees and shrubs were estimated after Kjeldahl digestion and titration using Kelplus Nitrogen Estimation System based on microkjeldahl distillation method (Bremner and Mulvaney 1982)

Data Analysis

One-way analysis of variance (ANOVA with Duncan's test for multiple comparisons) was conducted to analyze the effect of tree and shrub species on leaf mass, leaf area, SLA, and nitrogen concentration. A significance level of $P<0.05$ was used to determine statistical significance in all tests. A simple linear regression analysis was used to examine the relationships among leaf traits. All computations were done using the SPSS, ver. 16.0.

RESULTS

Leaf Phenology of Tree Species

The leafless period (i.e., deciduousness) and the leaf life span of different tree species in the three forests showed that *Acacia senegal* (L.) Willd., *Anogeissus pendula* Edegw, *Boswellia serrata* Roxb. ex Colebr. were of highly deciduous (HD) type as the life span of leaves was only 7 to 8 months. Eight tree species including *Azadirachta indica* A. Juss., *Cassia fistula* L., *Cordia dichotoma* Forst.f., *Derris indica* (Lamk.) Bennet, *Leucaena leucocephala* (Lamk.) de Wit, *Prosopis cineraria* (L.) Druce, *Prosopis juliflora* DC. and *Syzygium cumini* (L.) Skeels were least deciduous (LD) as the leaf span was about 11 months. 47.62 % of tree species like *Acacia leucophloea* (Roxb.) Willd., *Ailanthus excelsa* Roxb., *Albizia lebbeck* (L.) Benth., *Balanites aegyptiaca* (L.) Del., *Butea monosperma* (Lamk.) Taub., *Dalbergia sissoo* Roxb., *Diospyros cordifolia* Roxb., *Nyctanthes arbor-tristis* L., and *Ziziphus mauritiana* Lamk. were of short deciduous (SD) type in which leaf span varied from 9 to 10 months (Table 2).

Table 2. Some phenological leaf traits of tree species in the tropical dry forests at the three sites (based on Troup 1921, Jain et al. 2000).

Species	Family	Leaf Phenology	Leaf less Months	Leaf- Life Span
Acacia leucophloea (Roxb.) Willd.	Fabaceae - Mimosoideae	S D	Jan-March	9 Months
Acacia senegal (L.) Willd.	Fabaceae- Mimosoideae	H D	Jan - April	8 Months
Ailanthus excelsa Roxb.	Simaroubaceae	SD	April-May	10 Months
Albizia lebbeck (L.) Benth.	Fabaceae- Mimosoideae	S D	Jan-March	9 Months
Anogeissus pendula Edegw	Combretaceae	H D	Jan-April	8 Months
Azadirachta indica A. Juss.	Meliaceae	L D	March	11 Months
Balanites aegyptiaca (L.) Del.	Simaroubaceae	S D	Feb-March	10 Months
Boswellia serrata Roxb. ex Colebr.	Burseraceae	H D	Jan-May	7 Months
Butea monosperma (Lamk.) Taub.	Fabaceae	S D	Feb-March	10 Months
Cassia fistula L.	Fabaceae	L D	April	11 Months
Cordia dichotoma Forster f.	Boraginaceae	L D	March	11 Months
Dalbergia sissoo Roxb.	Fabaceae	S D	Jan-Feb.	10 Months
Derris indica (Lamk.)Bennet	Fabaceae	L D	March	11 Months
Diospyros cordifolia Roxb.	Ebenaceae	S D	Jan-Feb	10 Months
Kigelia pinnata (Jacq.) DC.	Bignoniaceae	S D	Feb-March	10 Months
Leucaena leucocephala (Lamk.) de Wit	Fabaceae- Mimosoideae	L D	Feb	11 Months
Nyctanthes arbor-tristis L.	Oleaceae	S D	March-May	9 Months
Prosopis cineraria (L.) Druce	Fabaceae - Mimosoideae	L D	Jan	11 Months
Prosopis juliflora (Sw.) DC.	Fabaceae- Mimosoideae	L D	Jan	11 Months
Syzygium cumini (L.) Skeels	Myrtaceae	L D	Feb	11 Months
Ziziphus mauritiana Lamk.	Rhamnaceae	S D	April-June	9 Months

HD= highly deciduous (≥ 4 months), SD= Short deciduous (> 2 to ≤ 3 months), LD=Least deciduous (≤ 1 month)

Leaf Attributes of Tree Species

This study includes four leaf attributes, i.e., leaf area, specific leaf area (SLA), leaf dry weight, and leaf N concentration which are referred to as functional attributes. Relationships of these functional attributes have been studied in different tree and shrub species of the three forests under field conditions. The leaf trait analysis is on per leaf basis. In the case of compound and bipinnately compound leaves, each leaflet/ pinna was measured separately to obtain values of leaf area and leaf weight. The leaf attributes showed wide variability among the tree species in all the three forests. Leaf area of 14 tree species in the *Ailanthus excelsa- Cassia fistula* (AE-CF) forest at Bhondsi varied from 12.58 cm^2 to 527.06 cm^2; the value being greatest in the case of *Cassia fistula* and minimum in the case of *Anogeissus pendula.* Correspondingly, the weight of leaves was 0.153 g and 2.701g for *Anogeissus pendula* and *Cassia fistula,* respectively (Table 3). The specific leaf area (SLA) was 81.64 to 231.19 $cm^2\ g^{-1}$; the variability in SLA being 2.83 fold among the tree species. The tree species such as *Butea monosperma, Cassia fistula*, *Derris indica,* and *Kigellia pinnata* with large compound leaves showed greater leaf area (527.06 to 209.01 cm^2) and leaf weight (2.701 to 0.906 g) imparting a favourable resource exploitation strategy associated with high SLA. In the case of tree species like *Anogeissus pendula*, and *Diospyros cordifolia*, the leaf area (12.58 to 10.48 cm^2) and specific leaf area (81.64 to 96.15 $cm^2\ g^{-1}$**)** were lower than in other species in the forest indicating their moderate resource acquisition for biomass accumulation.

In the case of *Acacia leucophloea-Balanites aegyptiaca* (AL-BA) forest at Gawalpahari, leaf area of tree species varied from 4.36 cm^2 to 364.00 cm^2; the value being greatest for *Butea monosperma* and minimum for of *Balanites aegyptiaca*. The leaf weight was 11.997g and 0.068g for *Butea monosperma* and *Balanites aegyptiaca*, respectively (Table 4). The specific leaf area ranged from 63.23 to 197.38$cm^2\ g^{-1}$; the variability in specific leaf area was found to be 3.12 fold among the tree species. In the case of *Acacia leucophloea* and *Balanites aegyptiaca* which were the predominant tree species in the forest, the values of different leaf traits were: 30.07 to 4.36 cm^2 leaf area, 0.348 to 0.068g leaf weight; 89.28 to 63.23cm^2g^{-1} specific leaf area.

Table 3. Mean leaf weight, specific leaf area (SLA) and N content of various tree species in the dry deciduous forest at Bhondsi, Gurgaon (Mean ± 1 SE)

Tree species	Leaf Weight (g)	Specific Leaf Area ($cm^2 g^{-1}$)	N (%)
Acacia leucophloea (Roxb.) Willd.	0.346 ±0.021	95.81 ±4.34	2.31 ±0.08
Acacia senegal (L.) Willd.	0.354 ±0.027	118.07 ±4.93	3.24 ±0.07
Ailanthus excelsa Roxb.	0.890 ±0.015	92.41 ±3.65	2.35 ±0.16
Anogeissus pendula Edegw	0.153 ±0.008	81.64 ±3.56	1.69 ±0.04
Azadirachta indica A. Juss.	0.443 ±0.008	90.78 ±2.78	1.87 ±0.04
Butea monosperma (Lamk.) Taub.	2.044 ±0.311	191.79 ±6.91	2.47 ±0.05
Cassia fistula L.	2.701 ±0.155	196.42 ±7.74	2.87 ±0.07
Dalbergia sissoo Roxb.	0.517 ±0.049	154.62 ±4.38	2.63 ±0.06
Derris indica (Lamk.)Bennet	0.906 ±0.032	231.19 ±4.19	3.37 ±0.05
Diospyros cordifolia Roxb.	0.109 ±0.005	96.15 ±4.63	2.31 ±0.03
Kigellia pinnata (Jacq.) DC.	2.318 ±0.119	125.41 ±4.25	1.60 ±0.04
Leucaena leucocephala (Lamk.) de Wit	0.108 ±0.004	199.28 ±8.44	3.42 ±0.05
Nyctanthes arbor-tristis L.	0.163 ±0.012	129.50 ±7.84	2.39 ±0.04
Syzygium cuminii (L.) Skeels	1.581 ±0.104	87.61 ±2.08	1.24 ±0.05

Table 4. Mean leaf area, leaf weight, and specific leaf area of various tree species in dry tropical forest at Gawalpahari, Gurgaon (Mean ±1 SE)

Tree species	Leaf weight (g)	Specific leaf area ($cm^2 g^{-1}$)	N (%)
Acacia leucophloea (Roxb.) Willd.	0.348 ±0.009	89.28 ±1.46	2.00 ±0.05
Azadirachta indica A. Juss.	0.465 ±0.008	88.25 ±2.89	1.85 ±0.04
Balanites aegyptiaca (L.)Del.	0.068 ±0.004	63.23 ±1.59	2.15 ±0.03
Butea monosperma (Lamk.) Taub.	1.997 ±0.242	181.65 ±4.23	2.33 ±0.05
Cordia dichotoma Forst.f.	0.457 ±0.007	197.38 ±5.92	1.18 ±0.02
Dalbergia sissoo Roxb.	0.639 ±0.074	108.21 ±5.69	2.49 ±0.09
Diospyros cordifolia Roxb.	0.103 ±0.006	99.33 ±4.67	2.21 ±0.04
Prosopis cineraria (L.) Druce	0.180 ±0.032	108.66 ±4.18	2.24 ±0.04
Prosopis juliflora DC.	0.230 ±0.023	81.45 ±5.09	2.32 ±0.06
Ziziphus mauritiana Lamk.	0.050 ±0.005	115.66 ±7.55	2.79 ±0.04

Table 5. Mean leaf area, leaf weight, and specific leaf area of various tree species in dry deciduous forest at Raisina (Mean ± 1 SE)

Tree species	Leaf weight (g)	Specific leaf area ($cm^2 g^{-1}$)	N (%)
Acacia leucophloea (Roxb.) Willd.	0.296 ±0.005	88.84 ±2.96	2.17 ±0.03
Acacia senegal (L.) Willd.	0.333 ±0.005	110.48 ±2.71	3.00 ±0.04
Anogeissus pendula Edgew	0.166 ±0.007	77.03 ±2.13	1.67 ±0.04
Boswellia serrata Roxb. ex Colebr.	0.204 ±0.015	63.57 ±3.63	1.25 ±0.05
Diospyros cordifolia Roxb.	0.138 ±0.007	73.57 ±3.29	2.23 ±0.03
Prosopis juliflora DC.	0.232 ±0.005	119.30 ±2.27	2.38 ±0.04

Leaf area of six tree species occurring in the *Anogiessus pendula- Acacia leucophloea* (*AP-AL*) forest at Raisina varied from 10.22 to 36.84 cm^2; the value being greatest in the case of *Acacia senegal*. The weight of leaves ranged from 0.138 to 0.333g for different tree species (Table 5). The specific leaf area ranged from 63.57 to 119.3cm^2 g^{-1}; the variability in SLA was found to be 1.88 fold among the tree species in this forest.

In all the three forests, there was a significant effect of tree species on leaf area, leaf weight, specific leaf area and nitrogen content (F= 45.16 to 94.53, P< 0.05 AE-CF forest at Bhondsi; F= 47.72 to 84.13, P< 0.05 AL-BA forest at Gawalpahari; F= 58.07 to 203.60, P< 0.05 AP-AL forest at Raisina).

Leaf Attributes of Shrub Species

In the dry deciduous forest at Bhondsi, *Adhatoda vasica*, *Capparis sepiaria* and *Carissa spinarum* were found to be important shrub species, *Capparis sepiaria* was the dominant shrub (IVI = 111.28) followed by *Adhatoda vasica* (IVI = 57.86) and *Carissa spinarum* (IVI=53.22). Leaf area of six shrub species in the AE-CF forest at Bhondsi varied from 2.85 cm^2 to 104.29 cm^2; the value being greatest in the case of *Adhatoda vasica* and minimum in the case of *Lycium europaeum. Calotropis procera* showed high leaf area (Figure 3). The weight of leaves ranged from 1.064 g to 0.057g for *Calotropis procera* and *Lycium europaeum*, respectively. In the AE-CF forest at Bhondsi, the specific leaf area ranged from 49.61 to 181.71 cm^2 g^{-1}; the variability in SLA was found to be 3.66 fold among the shrub species (Figure 4).

In the dry deciduous forest at Gawalpahari, shrub layer was composed of *Adhatoda vasica, Capparis sepiaria*, *Carissa spinarum, Lantana camara, Lycium europaeum* and *Maytenus emarginata; Capparis sepiaria* was the dominant shrub (IVI = 83.74) followed by *Carissa spinarum* (IVI = 65.58) and *Adhatoda vasica* (IVI = 48.99). The leaf area of seven shrub species ranged from 2.76 cm^2 to 96.32 cm^2; the value being greatest in the case of *Calotropis procera*. The weight of leaves was 0.997g and 0.086g, for *Calotropis procera* and *Lycium europaeum,* respectively *(*Figure 3). The specific leaf area ranged from 31.61 to174.12 cm^2g^{-1}; the variability in specific leaf area was found to be 5.51 fold among the shrub species (Figure 4).

The shrub layer in the Raisina forest was composed of *Adhatoda vasica, Capparis sepiaria,Calotropis procera*, *Carissa spinarum* and *Maytenus emarginata;* dominated by *Capparis sepiaria* (IVI= 110.61) followed by *Adhatoda vasica* (IVI = 99.45) and *Carissa spinarum*

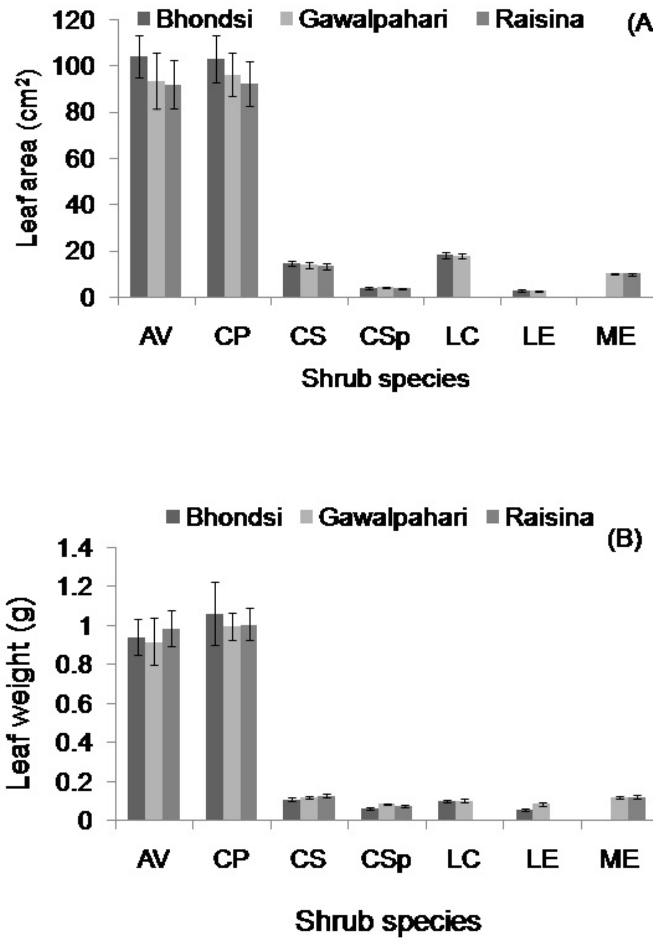

Figure 3. Variations in (A) leaf area and (B) leaf weight of shrub species in three forest sites of southern Haryana, India.
AV= *Adhatoda vasica* , CP= *Calotropis procera* , CS= *Capparis sepiaria* ,CSp= *Carissa spinarum* , LC= *Lantana camara* , LE= *Lycium europaeum* , ME= *Maytenus emarginata*

(IVI = 63.78). The leaf area of the shrub species varied from 3.69 cm^2 to 92.63 cm^2; the value being greatest in the case of *Calotropis procera* and minimum in the case of *Carissa spinarum* (Figure 4). The weight of leaves ranged from 1.007 g to 0.075g across species. The specific leaf area ranged from 48.73 to 102.67cm^2g^{-1}; the variability in SLA was found to be 2.11 fold among the shrub species in the forest at Raisina (Figure 4).

Nitrogen content in the leaves of shrub species in the three forests were: 1.20% to 2.92% forest at Bhondsi, 1.18% to 2.86% forest at Gawalpahari, 1.79% to 2.77% forest at Raisina. There were significant differences in nitrogen concentration in the leaves among the shrub species in the three forests (F=136.06, 153.15, 54.09; P<0.05).

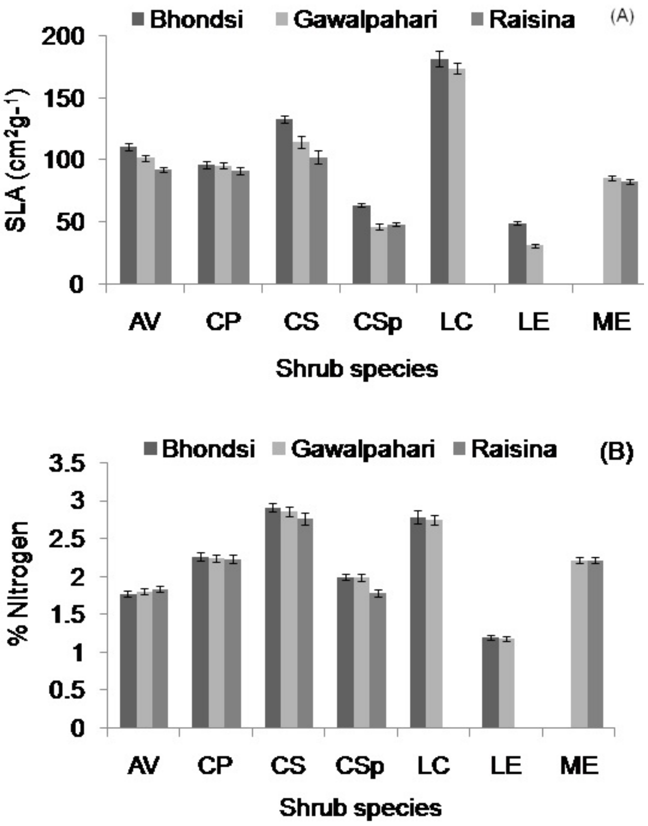

Figure 4. Variations in (A) Specific Leaf Area and (B) % Nitrogen concentration in leaves of shrub species in three forests of southern Haryana, India.
AV= *Adhatoda vasica* , CP= *Calotropis procera* , CS= *Capparis sepiaria* ,CSp= *Carissa spinarum* , LC= *Lantana camara* , LE= *Lycium europaeum* , ME= *Maytenus emarginata*

Relationship between Leaf Traits

In all the three forests, the leaf weight and leaf area were significantly correlated and accounted for 83% to 97 % variability in leaf area of the tree species (Figures 5 to 7). There was also significant relationship between SLA and leaf nitrogen content, which explained 55 to 67 % variability in nitrogen concentration due to variations in SLA among the tree species in the three forests (Figures 5 to 7).

In the case of shrub species in the three forests, the relationship between leaf weight and leaf area are given as :

AE-CF forest, Bhondsi,

$Y = 103.6X + 1.871; R^2 = 0.966,$

AL-BA forest, Gawalpahari

$Y = 100.5X - 0.866; R^2 = 0.984,$

AP-AL forest, Raisina

$Y = 95.50X - 1.727; R^2 = 0.992;$

where X is leaf weight (g) and Y is leaf area (cm^2).

From the above equations for the shrub species, it is evident that leaf weight and leaf area were significantly correlated , which explained 97 to 99 % variability in leaf area due to variations in leaf weight in the studied forests.

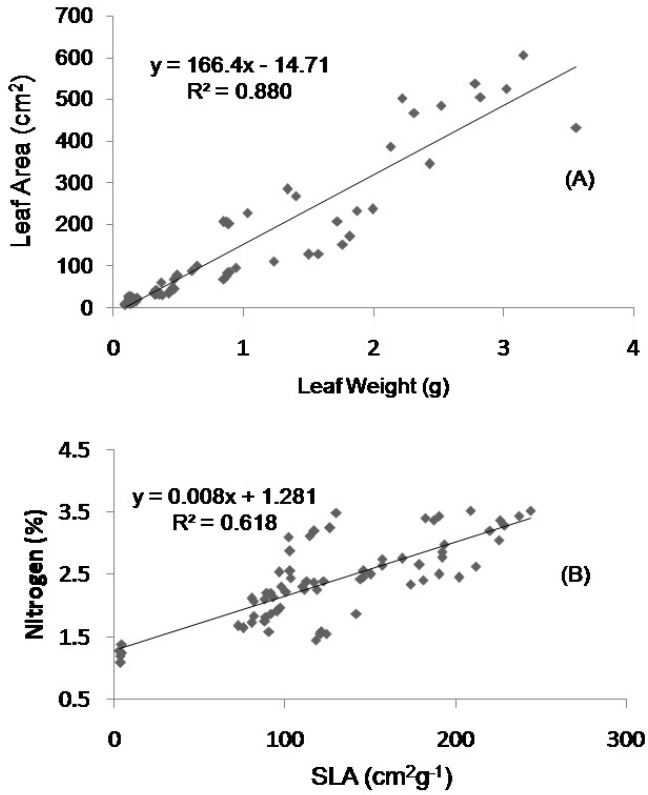

Figure 5. Regression relationship between (A) leaf area and leaf weight (B) SLA and nitrogen (%) of tree species in the dry deciduous forest at Bhondsi, Gurgaon.

DISCUSSION

Drought tolerance affects plant communities in tropical dry forests, which generally have three or more months of severe drought during the year (Mooney et al. 1995). In this study, the different tree species belonged to highly deciduous (three species), least deciduous (eight species), and short deciduous (10 species) types. The deciduousness of the tree species could be influenced by

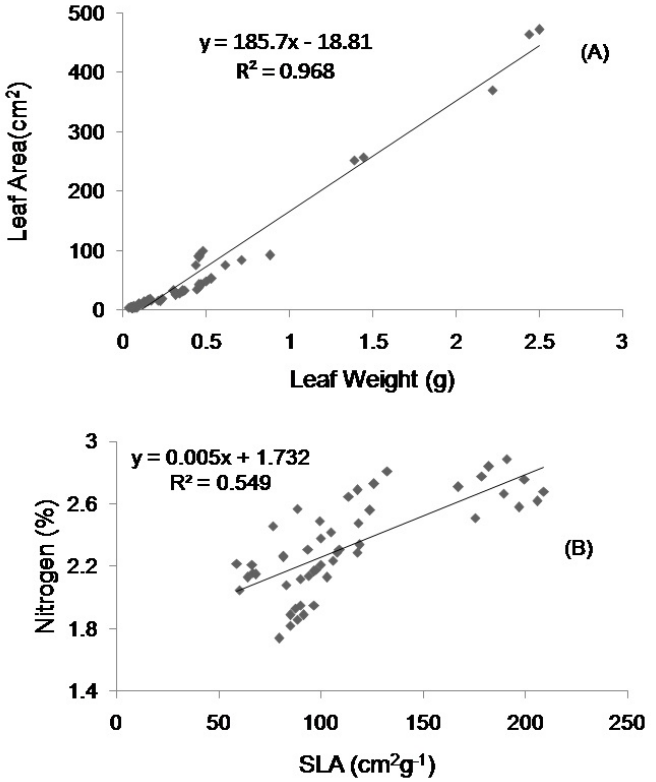

Figure 6. Regression relationship between (A) leaf area and leaf weight (B) SLA and nitrogen (%) of tree species in dry deciduous forest at Gawalpahari, Gurgaon.

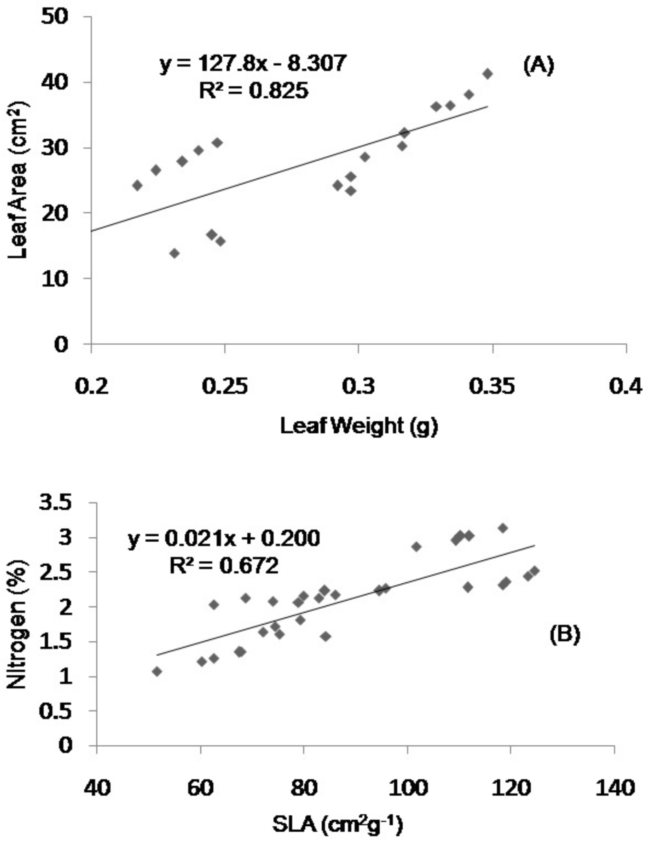

Figure 7. Regression relationship between (A) leaf area and leaf weight (B) SLA and nitrogen (%) of tree species in the dry tropical forest at Raisina, Gurgaon.

abiotic factors, which in turn affect intra- and inter-annual pattern of water, carbon and energy balance in the tropical dry deciduous forests (Bohlman 2010). Deciduousness (i.e., the leaflessness) is an important functional trait in the Vindhyan seasonally dry tropical forests of India (Singh and Kushwaha 2005). These workers reported that majority of tree species were< 2 month-deciduous (47%), 18 % 2-4 months deciduous, 13.5% were > 4 months deciduous and 21% were leaf exchange type. In this study, the tree species like *Acacia senegal*, *Anogeissus pendula*, *Boswellia serrata* were of highly deciduous (HD) type. The deciduous trees with more than four months leafless period exhibit rapid resource exploitation and conservation during a short growing season (Singh and Kushwaha 2005). According to Chaturvedi et al. (2011b), the leaf habit (i.e., deciduousness/ever greenness) is an important functional leaf trait so as to group plant species into ecologically relevant functional types.

The patterns of leaf traits varied in relation to the tree species composition in the three forests. It may be stated that differences in SLA are important for the coexistence of species as greater variation in SLA within a forest might allow different species to partition resources in response to variations in microtopography, and soil fertility. The plants species with high SLA tend to do better in resource-rich environments, while species with low SLA tend to perform better in resource-poor environments (Parkhurst and Loucks 1972). Several workers have reported that the tree species with low SLA and long leaf lifespan exhibit greater total foliage mass per unit ground area as compared to the species with higher SLA and shorter leaf lifespan (Reich et al. 1992, Gower et al. 1993; Read et al. 2006).

In the case of leguminous tree species such as *Acacia leucophloea*, *Acacia senegal,Prosopis juliflora,* and *Leucaena leucocephala* present in either of the three forests, the compound-leaves might help the plants to avoid high light intensity, high temperature, and excessive evaporation by folding of their leaflets at noon. The compound leaves have also been reported to increase leaf cooling and controlling water loss (Yates et al. 2010) besides serving effectively to increase leaf area for the capture of light (Niinemets 1998).

In this study, the tree species showed high variations in SLA among the tree species in the three forests. A comparison of SLA values between contrasting ecosystems in different regions of the world showed that the highest variation in SLA are found in the tropical dry forest ecosystems (Villar and Merino 2001). Variation in SLA for different trees in the three forests might be caused by variations in micro environmental conditions, soil water and soil properties. In this study, the total soil organic carbon pool in 15cm soil depth was greatest in the case of AE-CF forest at Bhondsi (7.38 Mg C ha^{-1}) followed by the forest at Raisina (6.41 Mg C ha^{-1}) and the AL-BA forest at Gawalpahari (4.92 Mg C ha^{-1}). It may be mentioned that there were variations in monthly average soil water content in the three forests. The leaf area and SLA were also found to be greater in the case of tree species in AE-CF forest at Bhondsi, whereas lower in the case of tree species occurring in the relatively dry forest at Raisina. Studies have shown that SLA and leaf area (LA) tend to decrease with decreasing moisture availability at the community level because of water availability and low nutrient status of soils (Medina et al. 1990; Cunningham et al. 1999; Fonseca et al. 2000; McDonald et al. 2003; Poorter 2009). Specific leaf area (SLA), leaf nitrogen content (LNC), leaf phosphorus content (LPC), and leaf N: P ratio tend to vary within and among species, and are known to be related to plant acquisition and use of resources (Wright et al. 2004, Chaturvedi et al. 2014).

There was positive a relationship between SLA (cm^2 g^{-1}) and nitrogen concentration in the case of both tree and shrub species in the three forests. SLA and leaf nitrogen content (LNC) of component species may have a significant impact on primary productivity and nutrient cycling at the ecosystem level (Reich et al. 1992, Cornelissen et al. 1999, Aerts and Chapin 2000). This is because of the fact that a combination of SLA and leaf nitrogen content can predict accurately the maximum photosynthetic rate of a wide range of species (Reich et al. 1997). Leaf nutrient concentration serves as a good indicator of plant nutritional status as well as soil nutrient availability (Van den Driessche 1974, Gusewell 2004). In a tropical dry deciduous forest in India, the intraspecific relative growth rate, SLA, leaf N, leaf P, and soil moisture content of six tree species were found to be positively interrelated (Chaturvedi et al. 2011a).

CONCLUSION

In the studied forests, majority of tree species were short deciduous (47.6%), 38.10% were least deciduous, 12.28% were highly deciduous. The tree species exhibited functional leaf trait variations in response to micro-topography, soil fertility, and soil water availability. The leaf area, leaf weight and specific leaf area varied among the tree species. Leaf weight and leaf area in the case of both tree and shrub species were significantly correlated as these are known to regulate plant acquisition and use of resources. The leaf attributes were significantly affected by species composition of the tree and understory shrub layer in the three forests. The trees belonging to family Fabaceae were predominant, which could be attributed to their adaptation to dry conditions because of the presence of compound leaves, high N leaf content, and low specific leaf area. The inter-specific differences in leaf attributes could play an important role in diversifying internal resource utilization and ecosystem functioning. The inter-specific differences in leaf attributes have a regulatory effect on biomass accumulation, litter decomposition, and ecosystem nutrient cycling. However, functional traits and their effects on the tropical dry deciduous forests need further research for predicting the dynamics of these forests under changing climate conditions.

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