Effects of Life-form and Plants Functional Traits on Carbon, Nitrogen and Sulfur Distributed in Different Parts in Dry Region of Western India

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Research

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Abstract

Background: Plants adapt to adverse environmental conditions accumulate varying concentrations of carbon (C), nitrogen (N) and sulfur (S) compounds to cope up with adverse climatic conditions. Carbon, N and S concentrations were determined in roots, stem and leaves of 33 species of trees/shrubs with objectives to observe the effects of life-form and plants functional traits, and select species with high concentration of these elements for their utilization in afforestation and medicinal uses.

Results: Concentrations of C, N, and S and C: N and N: S ratio varied ($P<0.05$) between species, organs, life-forms and functional traits (legume vs non-legume). These variables were higher (except C in roots and stem) in trees than shrubs, and in leguminous than non-leguminous species. Non-leguminous species showed high S content and low N: S ratio. Antagonistic and synergistic relations were observed between C and N, and N and S concentration respectively. Species showed varying potential in assimilating carbon by regulating uptake and accumulation of these elements in different organs making them adapt to the habitats affected by drought and salinity. We observed strong plant size/life-form effects on C and N content and C: N and N: S ratios and of function on S content.

Conclusions: Life-form/size and varying functions of the species determined C: nutrient ratio and elemental composition and helped adapting varying environmental stresses. This study assist in selecting species of high carbon, nitrogen and S content to utilize them in afforesting the areas affected by water and salt stresses, increased carbon storage and species with high S/N content in medicinal uses.

Background

The pathways of sulfur (S), carbon (C) and nitrogen (N) are well coordinated to maintain the physiological functions in plants (Giordano et al. 2000; Kopriva et al. 2002). Capacity of the plants to uptake and reallocate the element and consequently changes in the elemental composition and stoichiometry of the plant system are influenced by environmental conditions, altitude, soil texture and mineral elements availability (He et al. 2016; Shedayi et al. 2016). These mineral elements are reallocated by accumulation of metabolites along different pathways including *O*-acetylserine to serine to glycine, and are further channeled together with the nitrogen-rich compound glutamine into allantoin (Nikiforova et al. 2005). Likewise synthesis of cysteine from sulfide and *O*-acetyl-L-serine (OAS) is a reaction interconnecting sulfate, nitrogen, and carbon assimilation (Kopriva et al. 2002). Deficiency of any such element disrupts C: N: S ratio altering metabolic processes like decrease in cellular carbohydrate levels and respiration rate and breakdown of many complex organic molecules (Nikoforova et al. 2005; Dubousset et al. 2009) affecting biomass allocation (Lin and Wu 2004).

Allocation of these elements in above- and below-ground components of the plants is one of the key processes of their cycling and depends on species and soil or habitat types (Chen et al. 2015). Carbon allocation to shoots and roots is mediated by nitrogen supply via regulating cytokinins and sucrose production (Van der Werf and Nagel 1996). Wood C content also vary substantially among species ranging from 41.9–51.6%, but does not relate to ecological (i.e. wood density, maximum tree height), demographic (i.e. relative growth rate, mortality rate) or phylogentic traits (Martin and Thomas 2011). Some trees and shrubs show high ability to fix atmospheric carbon di oxide into their biomass with C content ranging from 51.66% in *Eugenia caryophyllata* to 47.77% in *Rosamarinus officinalis* (Maiti et al. 2015). Carbon concentration also vary with tree characteristics and tree organs like living branch > bark > foliage > dead branch > stem in aboveground and large roots > stumps > thick roots > medium roots > small roots in belowground organs (Wang et al. 2013). While C and N are used for structural macromolecules, sulfur has critical roles in the catalytic or electrochemical functions of the biomolecules in cells. Increased carbon concentration and total biomass is favoured by increased rate of carbon sequestration (i.e. rate of photosynthesis), whereas there is reduction in growth and biomass productivity under drought and a typical deficiency or insufficient supply of S or N. Sulfur deficiency also induces imbalance between carbon and nitrogen indicating importance of this nutrient on growth and productivity (Schonhof et al. 2007) and even tolerances to biotic and abiotic stresses in plants (Khan et al. 2014).

Species occurring in dry areas have ecological advantages of growing under varying biotic (human and livestock) and abiotic (limited soil water and increased salts) stresses and maintain higher abundances than the species that do not possess the characteristics of drought or salinity/alkalinity tolerances. In the context of the role of plants in capturing carbon dioxide from atmosphere and accumulate nitrogen and S metabolites in stressful conditions of dry areas, present study focused on (i) to determine C, N and S concentrations in various native and exotic species growing in Rajasthan, India; and (ii) to screen tree and shrub species with high carbon, sulfur and nitrogen content for increased carbon sequestration and adaptability in water/salt stressed region for their use in future afforestation programmes.

Methods

Site conditions

The study area is Rajasthan, which lies between latitudes 23º 3' and 30º 12' N and longitudes 69º 30' and 78º 17' E. Because of its location in the western part of India along with varying topography, Rajasthan exhibits varying climate. The rocky Aravali, the western arid plains, the eastern fertile plains etc., experience different climatic conditions. Long term average value of annual rainfall in Rajasthan is 575.1 mm. However, it varies widely among the districts ranging from 185.5 mm in Jaisalmer to 950.3 mm in Banswara (Fig. 1). Average annual rainfall for last 10 years is 663.3 mm with variations from 393.5 mm in 2009 to 851.8 mm in 2011 (Fig. 1). Average rainfall decreases from East to West and from South-west to North-east. There is marked decrease in rainfall west of the Aravalli range making the western Rajasthan arid.

Plant sampling and analysis

Plant samples were collected from exiting trees and shrubs species during 2010–2013. A total of 180 samples were taken from 19 trees and 14 shrubs species. After felling of the trees of different species, leaf, stem and root samples were collected. These samples were brought to laboratory and washed under the tap water for any soil and contaminants adhered to the samples and dried in hot air oven at 60–80°C for a constant weight. These dried plant samples were ground for a homogenous powder using a Tonko make Wiley Mill (no. 40 mesh). Powdered samples were then analyzed for Carbon (C), Nitrogen (N) and Sulfur (S) using CNS analyzer model (Flemetar make, Model - Vario EL Cube). In this about 20 mg fine ground wood/plant leaf samples were weighed using Mettler Toledo micro balance and the sample was put to the sampler of the CNS analyzer for combustion and C, N and S analysis using Sulphanilamide as the standard.

Statistical analysis

The data collected were statistically analyzed using SPSS statistical package version 8.0 for window 2000. Carbon, nitrogen and sulfur content in different parts like root, stem and leaves in different species were analyzed by two-way ANOVA, where tree/shrub species and their different organs were the main factors and number of trees/shrubs were the replicates. Data were also analyzed considering tree and shrubs as plant habits as well as considering leguminous and non-leguminous species. Data were also subjected to Pearson's correlation and regression analysis to find relationships between different mineral constituents. The least significant difference test was used to compare treatments at the $P < 0.05$ levels.

Results

Carbon concentration

Carbon concentration varied from 41.49–46.08% in roots, 42.71–55.27% in stem and 42.02–48.17% in leaves. Variations were significant ($P < 0.01$) between plant species and their organs both. Across the species, the lowest ($P < 0.05$) C concentration was in roots and highest in stem (Table 1). Almost 19 species showed the highest C concentration in leaves, 12 species (*Acacia senegal*, *Bauhinia racemosa*, *Capparis decidua*, *Mytenus emarginata*, *Prosopis cineraria*, *P. juliflora*, *Salvadora oleoides*, *Balanites aegyptiaca*, *Calligonum polygonoides*, *Calotropis procera*, *Leptadenia pyrotechnica*, and *Z. nummularia*) in stem, and two species (*Acacia jaquemontii* and *Haloxylan salicornicum*) in roots. When plant habit (trees vs shrubs) were considered, difference in carbon concentration was not significant ($P < 0.05$) in all three organs of trees and shrubs (Fig. 2a). Carbon concentration was significantly ($P < 0.05$) greater in roots and leaves of leguminous species than in non-leguminous species (Fig. 2b). Species with above average C concentration (44.80%) were *A. leucopheloea*, *A. nilotica*, *B. monosperma*, *C. mopane*, *H. binata*, *P. cineraria*, *P. juliflora*, *A. jaquemontii*, *B. aegyptiaca*, *C. polygonoides*, *E. caducifolia*, *H. antidyncenterica*, *R. mysorensis* and *Z. nummularia*.

Table 1

Per cent carbon content in different component of some trees and shrubs of Rajasthan. Values are mean ± SE of multiple replicates.

SNo.	Name of species	Life form	Carbon content (%, w/w)			
			Root	Stem	Leaves	Average
1	*Acacia catechu*	Tree	43.56 ± 0.45	43.05 ± 0.41	46.11 ± 1.12	44.31 ± 0.50
2	*Acacia leucopheloea*	Tree	44.31 ± 0.51	45.91 ± 0.23	46.08 ± 0.38	45.78 ± 0.16
3	*Acacia nilotica*	Tree	45.85 ± 2.31	43.85 ± 0.49	48.16 ± 0.92	46.03 ± 0.93
4	*Acacia senegal*	Tree	44.04 ± 0.99	45.79 ± 1.13	42.02 ± 0.34	43.92 ± 0.59
5	*Acacia tortilis*	Tree	44.17 ± 0.50	44.45 ± 0.21	45.92 ± 0.40	44.62 ± 0.26
6	*Ailanthus excelsa*	Tree	42.85 ± 1.31	43.61 ± 0.20	44.94 ± 0.73	44.80 ± 0.53
7	*Anogeissus pendula*	Tree	43.28 ± 0.47	44.86 ± 0.60	46.22 ± 0.38	43.52 ± 0.42
8	*Bauhinia racemosa*	Tree	43.49 ± 0.47	46.25 ± 0.40	44.87 ± 1.37	44.87 ± 0.71
9	*Butea monosperma*	Tree	42.23 ± 0.31	46.70 ± 1.79	47.84 ± 0.20	45.59 ± 0.71
10	*Capparis decidua*	Tree	42.15 ± 0.27	44.87 ± 0.89	43.47 ± 0.34	44.59 ± 0.93
11	*Cordia myxa*	Tree	41.49 ± 0.51	43.39 ± 0.48	43.57 ± 0.41	42.82 ± 0.16
12	*Colophospermum mopane*	Tree	43.70 ± 1.05	45.07 ± 0.29	47.78 ± 0.22	45.44 ± 0.35
13	*Hardwickia binata*	Tree	45.16 ± 0.70	45.17 ± 0.27	46.19 ± 0.15	45.51 ± 0.23
14	*Mytenus emarginata*	Tree	42.56 ± 0.62	44.12 ± 0.96	43.98 ± 0.67	43.26 ± 0.68
15	*Prosopis cineraria*	Tree	44.88 ± 0.95	45.72 ± 0.36	45.77 ± 0.41	45.77 ± 0.31
16	*Prosopis juliflora*	Tree	43.84 ± 0.73	46.73 ± 0.44	44.10 ± 0.70	46.27 ± 0.46

*US: undershrubs

SNo.	Name of species	Life form	Carbon content (%, w/w)			
			Root	Stem	Leaves	Average
17	*Salvaldora oleoides*	Tree	42.14 ± 0.88	43.99 ± 0.52	43.70 ± 0.52	43.28 ± 0.35
18	*Tecomella undulata*	Tree	43.95 ± 0.80	44.52 ± 0.72	44.89 ± 0.48	44.41 ± 0.25
19	*Ziziphus mauritiana*	Tree	42.82 ± 0.31	44.97 ± 0.43	45.36 ± 0.28	44.39 ± 0.33
20	*Acacia jacquemontii*	Shrub	45.59 ± 0.78	44.80 ± 0.77	45.16 ± 0.63	44.99 ± 0.56
21	*Adhatoda vasica*	US*	43.76 ± 0.74	42.71 ± 0.36	44.83 ± 0.28	43.77 ± 0.27
22	*Aerva pseudotomentosa*	US	42.49 ± 0.26	43.19 ± 0.28	43.37 ± 0.38	42.86 ± 0.18
23	*Balanites aegyptiaca*	Shrub	42.00 ± 0.27	47.24 ± 0.46	44.75 ± 0.22	46.27 ± 0.57
24	*Calligonum polygonoides*	Shrub	45.55 ± 0.49	46.38 ± 0.52	45.28 ± 0.37	45.73 ± 0.42
25	*Calotropis procrea*	Shrub	42.90 ± 0.59	45.40 ± 1.13	42.97 ± 0.93	43.76 ± 0.74
26	*Dichrostachys cineria*	Shrub	43.47 ± 0.72	44.59 ± 0.29	45.05 ± 0.13	44.30 ± 0.18
27	*Dypterigium glaucum*	US	43.31 ± 0.55	43.60 ± 0.39	45.37 ± 0.36	43.76 ± 0.32
28	*Euphorbia caducifolia*	Shrub	46.40 ± 1.50	55.27 ± 1.18	-	51.33 ± 0.16
29	*Haloxylan salicornicum*	US	43.89 ± 0.27	43.02 ± 0.79	-	43.46 ± 0.33
30	*H. antidyncenterica*	Shrub	45.14 ± 0.61	46.12 ± 0.47	47.17 ± 0.52	46.48 ± 0.33
31	*Leptadenia pyrotechnica*	Shrub	42.74 ± 0.15	44.98 ± 0.23	42.71 ± 0.19	43.77 ± 0.14
32	*Rhus mysorensis*	Shrub	44.80 ± 0.16	47.56 ± 0.20	46.40 ± 0.47	45.77 ± 0.12
33	*Ziziphus nummularia*	Shrub	45.22 ± 1.31	47.56 ± 1.25	45.59 ± 0.58	46.19 ± 0.80

*US: undershrubs

SNo.	Name of species	Life form	Carbon content (%, w/w)			
			Root	Stem	Leaves	Average
	Average		43.86 ± 0.15	45.22 ± 0.15	45.12 ± 0.15	44.90 ± 0.12

*US: undershrubs

Nitrogen concentration

Nitrogen concentration varied significantly ($P < 0.05$) in different organs of trees/shrubs species and ranged between 0.45% in the roots of *Acacia leucophloea* and 2.87% in the leaves of *Acacia nilotica* with an average value of 1.21 ± 0.04% across the species and the organs. Among the organs, average N concentration was highest in leaves (1.95 ± 0.06%) and lowest in stem (0.99 ± 0.03), whereas it was intermediate in roots (1.23 ± 0.04%) across the species and plant habits (Table 2). Twenty seven species showed highest N concentration in leaves, whereas it was highest in stem of *A. pseudotomentosa*, *Calotropis procera*, *E. caducifolia* and *H. salicornicum*, and in roots of *A. catechu* and *M. emarginata*. *A. tortilis*, *A. vasica, C. procrea, D. glaucum*, and *H. salicornicum* showed higher ($P < 0.05$) average N concentration than in the other species. Nitrogen concentration was greater ($P < 0.05$) in roots and leaves of trees species, whereas it was greater in stem of shrubs species (Fig. 3a). Leguminous and non-leguminous species showed highest ($P < 0.05$) N concentration in roots and leaves, and stem respectively (Fig. 3b). Some species like *A. tortilis* (2.65%), *A. nilotica* (2.87%), *A. senegal* (2.28%), *Ailanthus excelsa* (2.27%), *C. mopane* (2.07%), *H. binata* (1.97%), *Tecomella undulata* (2.91%), *P. cineraria* (1.95%), *P. juliflora* (2.76%), *Capparis decidua* (2.67%), *Bauhinia racemosa* (2.61%) and *A. jacquemontii* (2.51%), *Z. mauritiana* (2.44%) showed relatively high average N concentration.

Table 2

Per cent nitrogen content in different component of some trees/shrubs/undershrubs species of Rajasthan, India. Values are mean ± SE of multiple replicates.

SNo.	Name of species	Function	Nitrogen content (%, w/w)			
			Root	Stem	Leaves	Average
1	*Acacia catechu*	Legume	1.77 ± 0.22	1.29 ± 0.40	1.67 ± 0.06	1.58 ± 0.21
2	*Acacia leucopheloea*	Legume	0.82 ± 0.07	0.44 ± 0.04	1.22 ± 0.08	0.55 ± 0.06
3	*Acacia nilotica*	Legume	0.77 ± 0.15	0.59 ± 0.08	2.87 ± 0.21	1.41 ± 0.14
4	*Acacia senegal*	Legume	1.32 ± 0.23	0.92 ± 0.14	2.28 ± 0.16	1.45 ± 0.11
5	*Acacia tortilis*	Legume	2.23 ± 0.17	1.45 ± 0.10	2.65 ± 0.24	1.92 ± 0.11
6	*Ailanthus excelsa*	Non-legume	0.83 ± 0.02	1.16 ± 0.37	2.27 ± 0.19	1.42 ± 0.18
7	*Anogeissus pendula*	Non-legume	0.82 ± 0.05	0.73 ± 0.08	1.50 ± 0.41	0.85 ± 0.12
8	*Bauhinia racemosa*	Legume	1.18 ± 0.16	0.73 ± 0.12	2.61 ± 0.05	1.50 ± 0.07
9	*Butea monosperma*	Legume	0.88 ± 0.02	0.95 ± 0.12	1.17 ± 0.03	1.00 ± 0.03
10	*Capparis decidua*	Non-legume	1.95 ± 0.31	1.30 ± 1.78	2.67 ± 0.06	1.48 ± 0.19
11	*Cordia myxa*	Non-legume	1.40 ± 0.17	1.42 ± 0.04	1.71 ± 0.03	1.51 ± 0.05
12	*Colophospermum mopane*	Legume	0.64 ± 0.06	0.56 ± 0.04	2.07 ± 0.05	1.03 ± 0.05
13	*Hardwickia binata*	Legume	0.80 ± 0.03	0.51 ± 0.03	1.97 ± 0.15	1.10 ± 0.04
14	*Mytenus emarginata*	Non-legume	1.69 ± 0.55	0.98 ± 0.40	1.03 ± 0.05	1.38 ± 0.44
15	*Prosopis cineraria*	Legume	1.29 ± 0.21	0.78 ± 0.04	1.92 ± 0.15	0.99 ± 0.94
16	*Prosopis juliflora*	Legume	1.79 ± 0.17	0.87 ± 0.16	2.76 ± 0.33	1.20 ± 0.19
17	*Salvaldora oleoides*	Non-legume	1.25 ± 0.09	1.25 ± 0.22	1.36 ± 0.15	1.29 ± 0.04

SNo.	Name of species	Function	Nitrogen content (%, w/w)			
			Root	Stem	Leaves	Average
18	*Tecomella undulata*	Non-legume	0.53 ± 0.09	0.57 ± 0.08	2.91 ± 0.15	1.18 ± 0.18
19	*Ziziphus mauritiana*	Non-legume	0.56 ± 0.05	0.52 ± 0.01	2.44 ± 0.06	1.18 ± 0.02
20	*Acacia jacquemontii*	Legume	0.96 ± 0.14	0.81 ± 0.06	2.51 ± 0.12	1.17 ± 0.10
21	*Adhatoda vasica*	Non-legume	2.28 ± 0.08	2.28 ± 0.05	2.65 ± 0.03	2.40 ± 0.04
22	*Aerva pseudotomentosa*	Non-legume	0.94 ± 0.04	1.26 ± 0.08	0.92 ± 0.02	1.10 ± 0.04
23	*Balanites aegyptiaca*	Non-legume	1.15 ± 0.15	0.70 ± 0.04	1.84 ± 0.03	0.89 ± 0.09
24	*Calligonum polygonoides*	Non-legume	0.95 ± 0.06	0.81 ± 0.04	1.33 ± 0.11	0.91 ± 0.04
25	*Calotropis procrea*	Non-legume	1.64 ± 0.13	1.92 ± 0.26	1.76 ± 0.41	1.77 ± 0.12
26	*Dichrostachys cineria*	Legume	1.51 ± 0.14	1.20 ± 0.16	1.90 ± 0.07	1.44 ± 0.13
27	*Dypterigium glaucum*	Non-legume	2.08 ± 0.22	1.67 ± 0.10	2.64 ± 0.09	2.00 ± 0.09
28	*Euphorbia caducifolia*	Non-legume	0.67 ± 0.03	1.35 ± 0.10	-	1.01 ± 0.04
29	*Haloxylan salicornicum*	Non-legume	1.80 ± 0.11	1.91 ± 0.23	-	1.86 ± 0.12
30	*H. antidyncenterica*	Non-legume	1.04 ± 0.04	1.39 ± 0.09	1.44 ± 0.06	1.29 ± 0.03
31	*Leptadenia pyrotechnica*	Non-legume	0.97 ± 0.11	1.08 ± 0.18	1.31 ± 0.15	1.05 ± 0.13
32	*Rhus mysorensis*	Non-legume	0.56 ± 0.04	0.57 ± 0.03	0.88 ± 0.01	0.74 ± 0.01
33	*Ziziphus nummularia*	Non-legume	0.81 ± 0.07	0.81 ± 0.07	1.27 ± 0.20	0.94 ± 0.08
	Average		1.22 ± 0.04	0.99 ± 0.03	1.95 ± 0.06	1.21 ± 0.04

Table 3

Per cent sulfur content in different component of some trees/shrubs/undershrubs species of Rajasthan. Values are mean ± SE of multiple replicates.

SNo.	Name of species	Sulfur content (%, w/w)			
		Root	Stem	Leaves	Average
1	*Acacia catechu*	0.60 ± 0.52	0.33 ± 0.29	0.06 ± 0.00	0.33 ± 0.27
2	*Acacia leucopheloea*	0.07 ± 0.01	0.03 ± 0.00	0.13 ± 0.01	0.04 ± 0.01
3	*Acacia nilotica*	0.04 ± 0.02	0.02 ± 0.01	0.18 ± 0.06	0.10 ± 0.03
4	*Acacia senegal*	0.16 ± 0.06	0.06 ± 0.02	0.14 ± 0.01	0.13 ± 0.01
5	*Acacia tortilis*	0.28 ± 0.03	0.20 ± 0.06	0.31 ± 0.06	0.25 ± 0.03
6	*Ailanthus excelsa*	0.09 ± 0.01	0.11 ± 0.02	0.19 ± 0.05	0.13 ± 0.02
7	*Anogeissus pendula*	0.09 ± 0.01	0.08 ± 0.01	0.19 ± 0.02	0.09 ± 0.01
8	*Bauhinia racemosa*	0.02 ± 0.01	0.03 ± 0.02	0.07 ± 0.00	0.04 ± 0.01
9	*Butea monosperma*	0.06 ± 0.01	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.01
10	*Capparis decidua*	1.42 ± 0.29	1.10 ± 0.10	1.45 ± 0.03	1.12 ± 0.12
11	*Cordia myxa*	0.08 ± 0.00	0.05 ± 0.00	0.12 ± 0.06	0.10 ± 0.01
12	*Colophospermum mopane*	0.01 ± 0.01	0.03 ± 0.02	0.11 ± 0.01	0.05 ± 0.01
13	*Hardwickia binata*	0.09 ± 0.01	0.01 ± 0.01	0.24 ± 0.03	0.11 ± 0.01
14	*Mytenus emarginata*	0.17 ± 0.05	0.09 ± 0.03	0.24 ± 0.05	0.16 ± 0.04
15	*Prosopis cineraria*	0.25 ± 0.04	0.07 ± 0.01	0.22 ± 0.01	0.12 ± 0.02
16	*Prosopis juliflora*	0.40 ± 0.05	0.10 ± 0.02	0.40 ± 0.05	0.18 ± 0.03
17	*Salvaldora oleoides*	1.17 ± 0.10	2.07 ± 0.58	2.28 ± 0.19	1.84 ± 0.24
18	*Tecomella undulata*	0.05 ± 0.01	0.10 ± 0.06	0.20 ± 0.02	0.11 ± 0.03
19	*Ziziphus mauritiana*	0.04 ± 0.01	0.06 ± 0.02	0.10 ± 0.01	0.07 ± 0.01
20	*Acacia jacquemontii*	0.20 ± 0.05	0.09 ± 0.02	0.27 ± 0.05	0.16 ± 0.03
21	*Adhatoda vasica*	0.33 ± 0.11	0.15 ± 0.02	0.45 ± 0.13	0.31 ± 0.05
22	*Aerva pseudotomentosa*	0.14 ± 0.01	0.13 ± 0.02	0.05 ± 0.01	0.14 ± 0.01
23	*Balanites aegyptiaca*	0.28 ± 0.04	0.18 ± 0.08	0.39 ± 0.02	0.20 ± 0.04
24	*Calligonum polygonoides*	0.44 ± 0.04	0.26 ± 0.02	0.20 ± 0.04	0.34 ± 0.02

SNo.	Name of species	Sulfur content (%, w/w)			
		Root	Stem	Leaves	Average
25	*Calotropis procrea*	0.38 ± 0.11	0.31 ± 0.10	0.22 ± 0.10	0.30 ± 0.05
26	*Dichrostachys cineria*	0.15 ± 0.03	0.14 ± 0.03	0.13 ± 0.01	0.14 ± 0.02
27	*Dypterigium glaucum*	1.13 ± 0.12	0.56 ± 0.03	0.96 ± 0.06	0.87 ± 0.06
28	*Euphorbia caducifolia*	0.22 ± 0.07	1.22 ± 0.10	-	0.72 ± 0.02
29	*Haloxylan salicornicum*	0.10 ± 0.03	0.09 ± 0.02	-	0.10 ± 0.02
30	*H. antidyncenterica*	0.04 ± 0.01	0.08 ± 0.00	0.04 ± 0.01	0.06 ± 0.00
31	*Leptadenia pyrotechnica*	0.09 ± 0.01	0.15 ± 0.02	0.10 ± 0.02	0.12 ± 0.01
32	*Rhus mysorensis*	0.06 ± 0.00	0.10 ± 0.02	0.07 ± 0.01	0.10 ± 0.01
33	*Ziziphus nummularia*	0.03 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.00
	Average	0.26 ± 0.02	0.21 ± 0.02	0.30 ± 0.09	0.24 ± 0.02

Sulfur concentration

Concentration of S ranged between 0.01% and 1.17% in roots, 0.01% and 2.07% in stem, and 0.04% and 2.28% in leaves across the species and plant habits. Among the organs, average S concentration varied significantly ($P < 0.05$) and it was highest in leaves (0.30 ± 0.09%) followed by roots (0.26 ± 0.02%) and stem (0.21 ± 0.02%). Almost 19 species under study showed highest concentration of S in leaves, whereas 10 species namely *A. catechu*, *A. senegal*, *P. cineraria*, *P. juliflora*, *A. pseudotomentosa*, *C. polygonoides*, *C. procera*, *D. cineria*, *D. glaucum*, *H. salicornicum* had highest S concentration in roots. Four species like *E. caducifolia*, *H. antidyncenterica, L. pyrotechnica* and *R. mysorensis* showed greater S in stem than in the other organs. Though not significant ($P > 0.05$), S concentration was relatively greater in all three organs of trees as compared to those in the shrub species (Fig. 4a). However, S concentration was significantly ($P < 0.05$) greater in all these organs of non-leguminous species as compared to leguminous species when functional aspect was considered (Fig. 4b). Among the species *Capparis decidua*, *S. oleoides*, *Dypterigium glaucum* and *Euphorbia caducifolia* showed significantly ($P < 0.05$) higher average S concentration than the other species. Out of 33 species studied, 9 species (4 tree species and 5 shrub species) indicated above average (0.24%) sulfur concentration.

Carbon: N and N: S ratios

Carbon to nitrogen ratio ranged from 18.24 for *Adhatoda vasica* to 79.27 for *P. juliflora* with an average value of 32.42. Nitrogen to sulfur ratio varied from 0.74 for *Salvadora oleoides* to 36.68 in case of *C. mopane* with an average value of 12.76 across the species (Fig. 5). Both C: N and N: S ratios were greater for tree species than for shrub species between plant habits. These ratios were greater in leguminous species than the non-leguminous species. Seven species of shrubs and 11 species of trees showed below average C: N ratio (Fig. 5). Almost 8 tree species and 5 shrub species showed C: N ratio below 35. *P. juliflora* showed highest ($P < 0.05$) C: N ratio. *Anogeissus pendula*, *B. racemosa*, *C mopane*, *H. salicornicum, H. antidycenterica*, and *Z. nummularia* showed highest ($P < 0.05$) average N: S ratio (> 20). *S. oleoides* showed lowest N: S ratio, but it did not differed in this ratio for other 26 species. Species with N:S ratio below 10 were *A. tortilis*, *C. decidua*, *Maytenus emarginata*, *P. cineraria*, *S. oleoides*, *Adhatoda vasica*, *B. aegyptiaca*, *C. polygonoides*, *C. procera*, *D. glaucum*, *E. caducufolia*, *L. pyrotechnica*, which come naturally in the area influenced by drought or salinity.

Statistical relations

Average stem carbon in plant was negatively correlated to root (r=-0.160, $P < 0.05$), stem (r=-0.199, $P < 0.01$) and leaf (r=-0.282, $P < 0.01$) nitrogen and leaf (r=-0.193, $P < 0.05$) sulfur and positively correlated to C: N ratio ($r = 0.331$, $P < 0.01$). Likewise leaf C concentration showed negative relationships with root (r=-0.285, $P < 0.01$), and stem (r=-0.290, $P < 0.01$), nitrogen and sulfur (r=-0.234 and r=-0.182, $P < 0.01$) and positive relationships with C: N ratio ($r = 0.277$, $P < 0.01$), and N: S ratio ($r = 0.286$, $P < 0.01$). Nitrogen concentration in root and stem was positively related to sulfur concentration in root ($r = 0.457$ and $r = 0.327$, $P < 0.01$), stem ($r = 0.194$ and $r = 0.314$, $P < 0.01$) and leaf ($r = 0.291$ and $r = 0.240$, $P < 0.01$), but negatively related to N: S ratio (r=-0.109 and r=-0.152, $P < 0.05$). Carbon concentration decreased with increase in nitrogen concentration by a power of 0.03 ($R^2 = 0.134$, SEE = 0.041 $F_{1/285} = 44.55$, $P < 0.01$), whereas nitrogen concentration increased with increase in sulfur concentration in plant system by a power of 0.259 ($R^2 = 0.344$, SEE = 0.406, $F_{1/283} = 149.67$, $P < 0.01$) (Fig. 6).

Discussion

Species with high carbon content and biomass production (carbon storage) favour carbon sequestration and consequently reduction in atmospheric carbon dioxide load (Fekete et al. 2017). Variations($P < 0.05$) in C, N and S contents between the species showed species dependent uptake and accumulation of these elements as a tolerance mechanism to varying environmental factors like availability of S and N in the soils (Zhang et al. 2013; Singh and Singh 2009). Dissimilarity ($P < 0.05$) in C: N and N: S ratios between the species also suggest the role of species functional traits in balancing elemental composition in a particular environment (Abbas et al. 2013). Relatively high carbon content in *A. leucopheloea*, *A. nilotica*, *B. monosperma*, *C. mopane*, *H. binata*, *P. cineraria*, *P. juliflora*, *A. jaquemontii*, *B. aegyptiaca*, *C. polygonoides*, *E. caducifolia*, *H. antidycenterica*, *R. mysorensis* and *Z. nummularia* as compared to the other species exhibited varying capacity of conversion of atmospheric CO_2 to organic carbon stored in plants biomass (Navarro et al. 2013). Decrease in soil water availability reduces uptake of N or other nutrients (Waraich et al. 2011) and suggests a negative feedback of low water and nutrients on the production capacity and suitability of plants growing in dry areas, where plants are affected by droughts of varying intensity and tend to increase C: N/S ratios (Limousin et al. 2010). Increased plant activity and growth is also linked with a dilution of nutrients that leads to decreases in N concentrations and increased C: N ratio (Sardans et al. 2012).

Among different organs, carbon, N and S concentration were observed in the descending order of Stem > leaves > root, leaves > roots > Stem and leaves > root > stem respectively, across the species. Global analysis of plant carbon content also indicated highest C content in stem, whereas leaves showed greater C than roots (Ma et al. 2017). Major contribution on interspecies variation in these elements among the species was due to differences in the chemical constituents of wood, i.e. cellulose, lignin and non-structural carbohydrates (Elias and Potvin 2003; Martin and Thomas 2011). The variations in C, N, S concentrations and C: N or N: S ratios between plant organs depends upon availability of soil water and nutrients (N, P, S etc.) as C: N ratio in stem and roots increased with decrease in soil N availability and uptake (Di Palo and Fornara 2015). *Larix olgensis* also showed carbon distribution like: living branch > bark > foliage > dead branch > stem > below ground (Wang et al. 2013).

Relatively higher concentrations of both nitrogen and sulfur (> 0.3%) in *Adhatoda vasica*, *C. procera* and *D. gluacum*, nitrogen in *A. tortilis* and *H. salicornicum* and sulfur in *Acacia catechu*, *C. polygonoides*, *C. decidua*, *S. oleoides* and *E. caducifolia* appeared related to habitats with low water (sand dunes and rocky areas) and high salt concentration (saline/alkaline areas). Increased concentrations of both N and S content in some species revealed that these nutrients are highly inter-related in plants as indicated by a positive relationship between N and S concentrations ($r = 0.337$, $P < 0.01$, Fig. 3). Significantly ($P < 0.5$) high concentrations of N and S in the leaves might help to assimilate carbon dioxide at higher rate favouring carbon sequestration. Increased concentration of sulfur in the foliage, i.e. from 0.20–0.45% favour synthesis of photosynthates and growth but it also depends upon N: S ratio (Terry 1976; Hu and Sparks 1992). In contrary, nutrient limitation as observed in dry areas in general results in reduced growth rate, cell volume, and photosynthetic activity (due to substantial decline in Rubisco and chlorophyll *a*/*b*-binding proteins under sulfur-limited environment (Gilbert et al. 1997). Such adaptation appeared mediated by an array of physiological responses that strongly suggest regulatory interactions between the assimilatory pathways of S, N and C (Kopriva et al. 2002). Nitrogen to S ratio in the phytomass is also a measure of sulfur requirements than the element's absolute level and this ratio is tightly regulated in plant tissues so as to maintain it in the range of 20: 1 to 35: 1 to fulfill the human dietary requirements (Ingenbleek 2006) though low ratio have also reported for many plant species grown in different stressful environment (Lakkineni and Abrol 1993). Almost 22 species in present study showed N: S ratio < 15 (average S concentration 0.11–1.84%) indicating their adaptation either to drought or salinity. Linzon et al. (1979) have also observed a medium concentration (0.16–0.26%) of S in the foliage of evergreen trees and some deciduous trees and shrubs. A positive relationship between N and S concentration indicates the impact of N source on different steps of N and S metabolism, i.e. inducing N and S assimilation influencing growth and carbon sequestration (Coleto et al. 2017).

Significant variations in C, N and S concentrations and C: N or N: S ratios between trees and shrubs as well as leguminous and non-leguminous in different organs indicates the influence of life forms/plant habits and functional group identity on plant C to nutrient stoichiometry indicated by higher concentrations of C (leaves), N (roots and leaves), S (all organs) and C: N and N: S ratios in trees as compared to the shrubs. Likewise, higher C, N (roots and leaves), and C: N and N: S ratio in leguminous species and that of S concentration in non-leguminous species explains the functional role of these species in N and S metabolism. However, some studies showed antagonistic effects of leguminous crop on C: N ratio (Di Palo and Fornara 2015). Despite of leguminous in nature higher C: N ratio in these plants as compared to the non-leguminous plants suggests the influence of life form/size of the plants on this ratio (Sardans et al. 2012). Relatively higher S concentration and reduced N: S ratio in most of the species under study was due to modulation of sulfur metabolites production altering physiological and molecular mechanisms to provide tolerance against salinity and droughts (Khan et al. 2014). It was also indicated by enhanced plant stress-defense mechanism by S fertilization to high S-loving plants like Brassicas and leguminous crops (Naser et al. 2012). However, under deficiency, interdependent nutrients S and N play significant role in the maintenance of the status of S-compounds, and S-N homeostasis (Naser et al. 2015).

Conclusion And Recommendations

Present study illustrates large variability in C, N and S concentration between trees/shrubs species and their different organs (roots, stem and leaves) as well. As adaptation characteristics towards drought and salinity stresses, these species regulated concentration and stoichiometry of these elements in the region. Increased C: N and N: S ratios were found related to increase in plant size (tree vs shrubs). However, increased concentration of S and reduced N: S ratio in non-leguminous plants showed their adaptability of growing in habitats affected by drought and salinity stresses. Therefore, different tree and shrubs species have different potential to assimilate carbon by regulating uptake and accumulation of sulfur, nitrogen, and carbon in different organs. *A. leucopheloea*, *A. nilotica*, *B. monosperma*, *C. mopane*, *H. binata*, *P. cineraria*, *P. juliflora*, *A. jaquemontii*, *B. aegyptiaca*, *C. polygonoides*, *E. caducifolia*, *H. antidyncenterica*, *R. mysorensis* and *Z. nummularia* observed high in average C content, whereas *Capparis decidua*, *S. oleoides*, *Dypterigium glaucum* and *Euphorbia caducifolia* observed high in S content. This study offered an opportunity for the selection of species with high carbon, nitrogen and S content for their use in greening the areas affected by water and salt stresses, increased carbon storage and in pharmaceuticals particularly the species with high S-N content.

Declarations

Availability of data

The datasets used and/or analyzed during the current study are available from the corresponding author on request.

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Contributions

Both authors contributed to the study, material preparation, data collection, analysis and writing of the manuscript. Both authors read and approved the final manuscript.

Ethics declaration

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

Authors declare that they have no competing interest.

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Figures

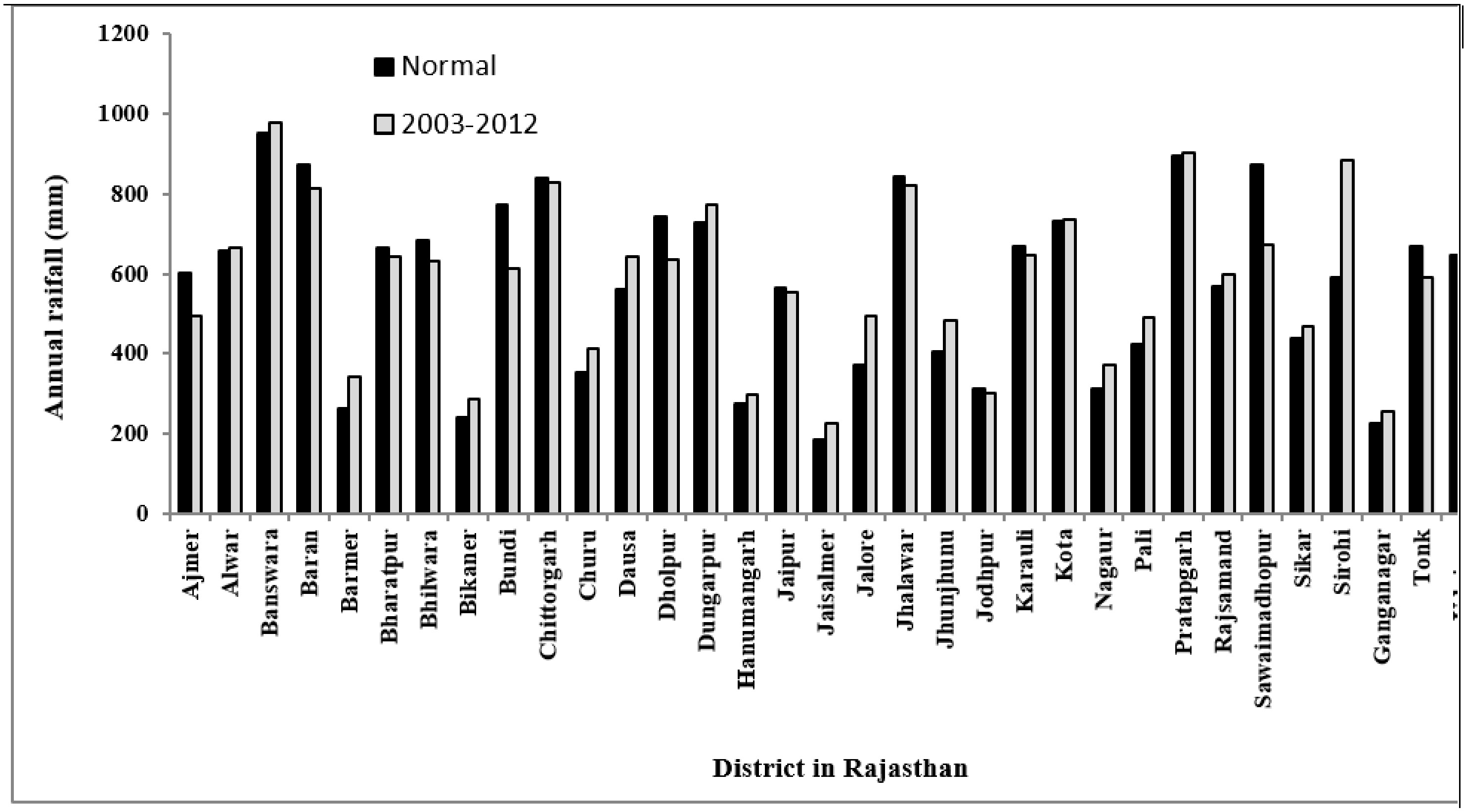

Figure 1

Average annual rainfall (long term and during 2003-12) distribution in different districts of Rajasthan, India.

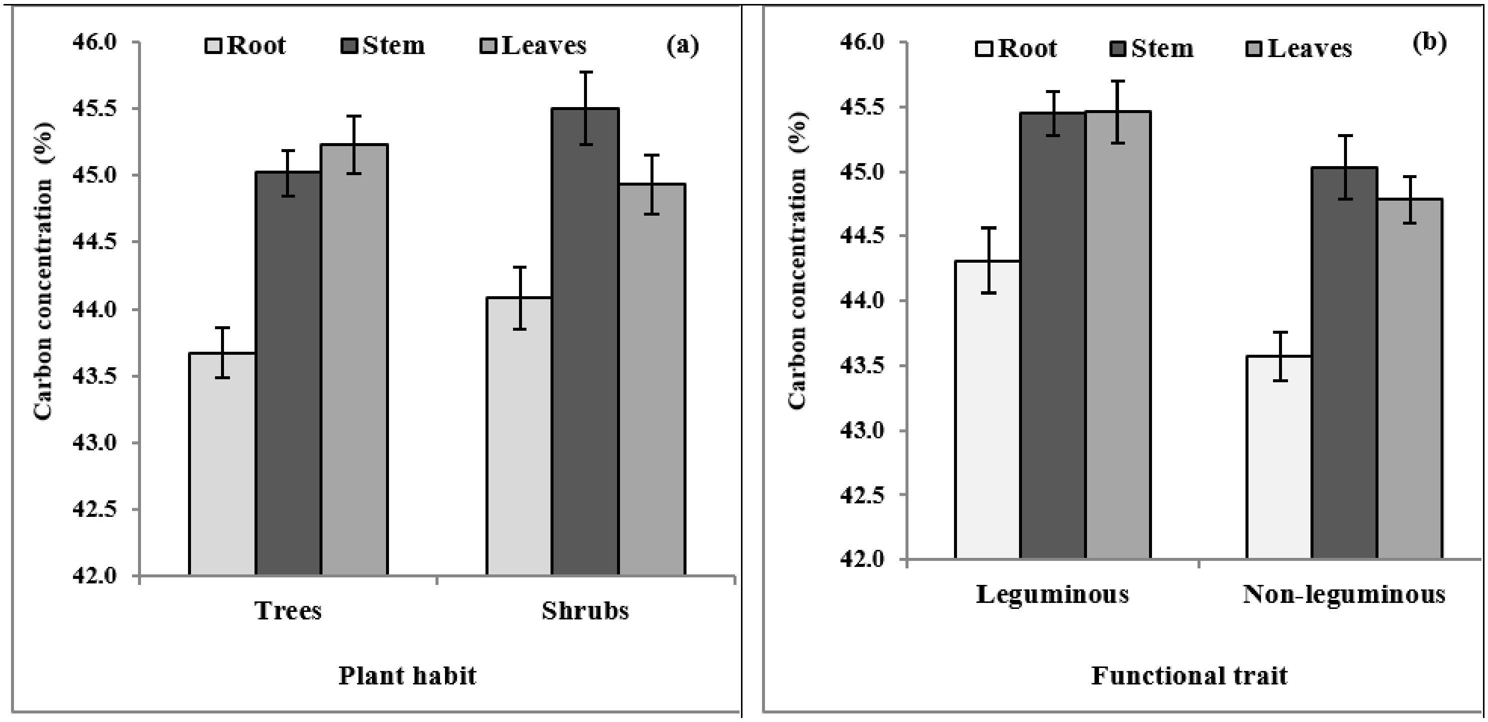

Figure 2

Variations in carbon concentration in different organs of the plants due to plant habit (tree vs shrubs, a) and functional traits (leguminous vs non-leguminous, b) in Rajasthan, India.

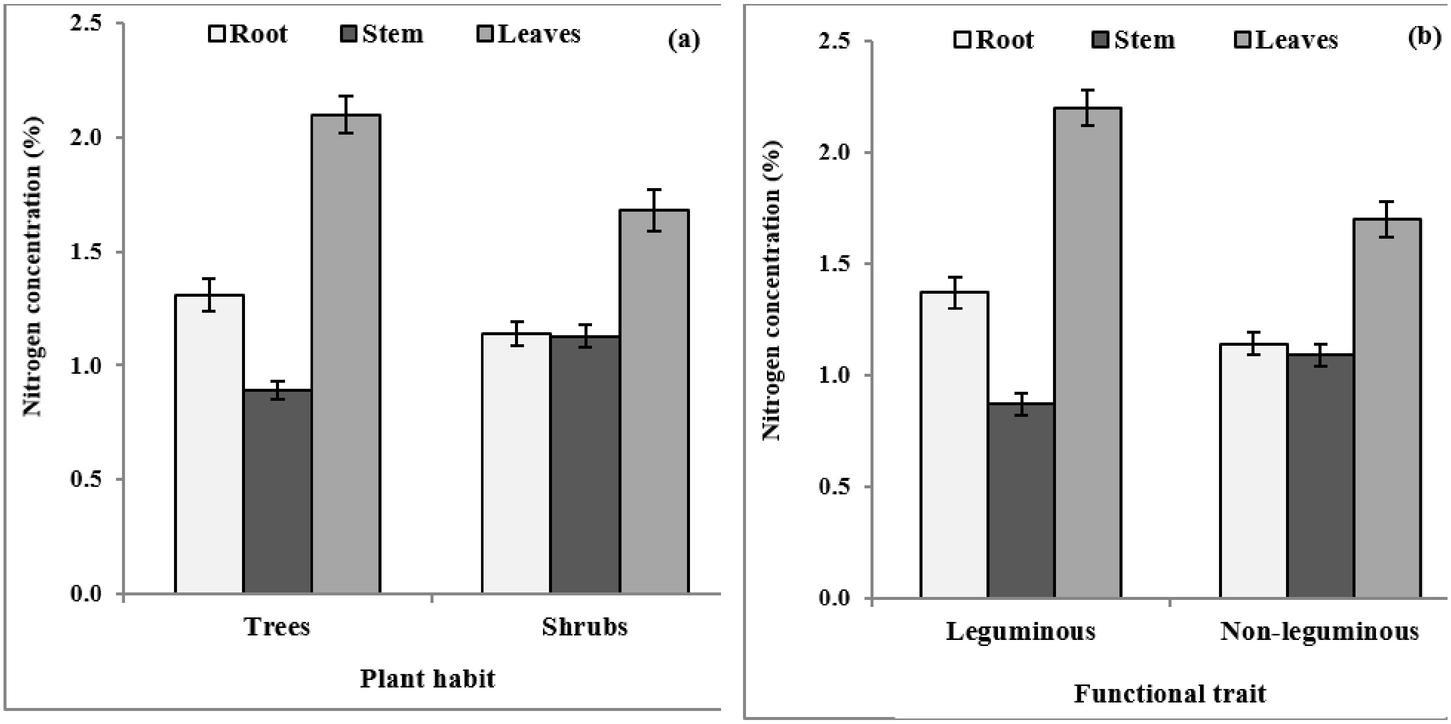

Figure 3

Variations in nitrogen concentration in different organs of the plants due to plant habit (tree vs shrubs, a) and functional traits (leguminous vs non-leguminous, b) in Rajasthan, India.

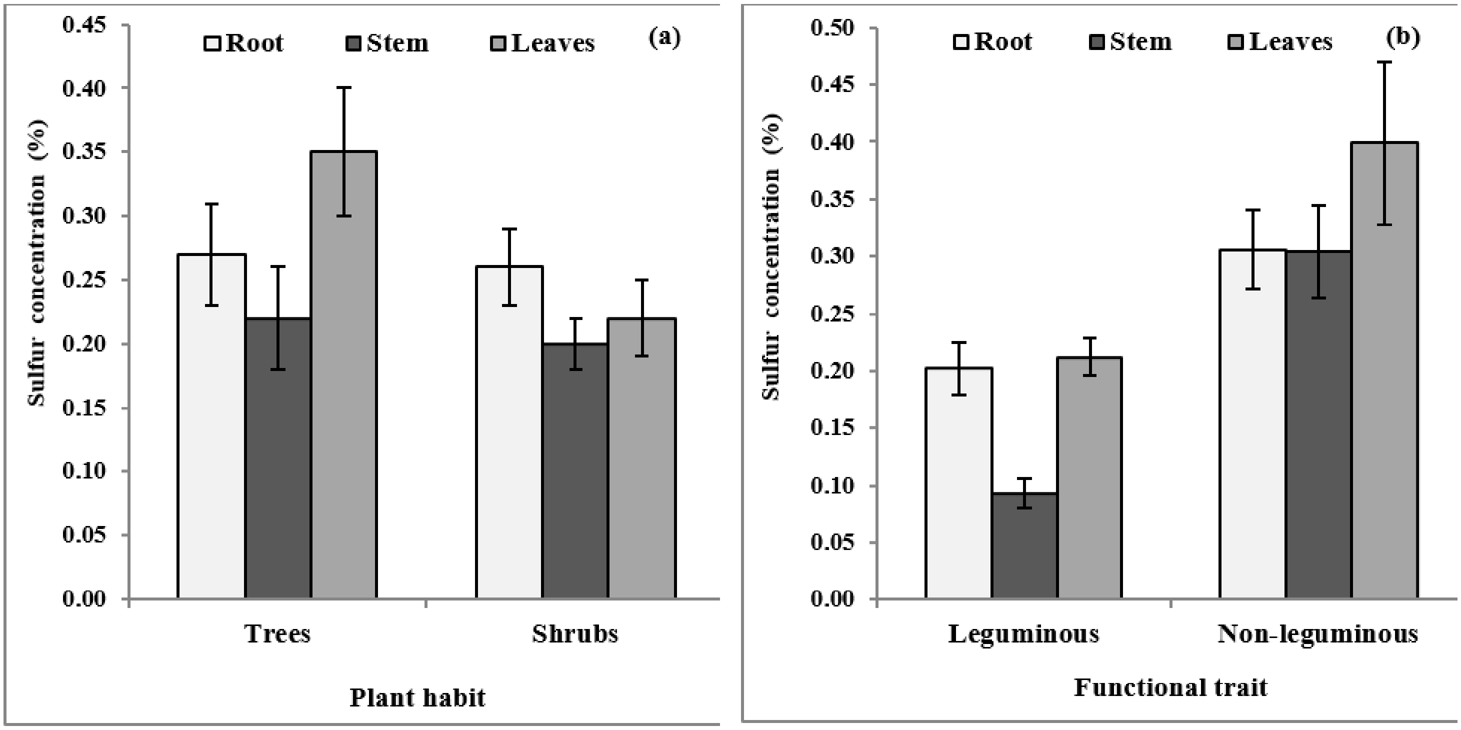

Figure 4

Variations in sulfur concentration in different organs of the plants due to plant habit (tree vs shrubs, a) and functional traits (leguminous vs non-leguminous, b) in Rajasthan, India

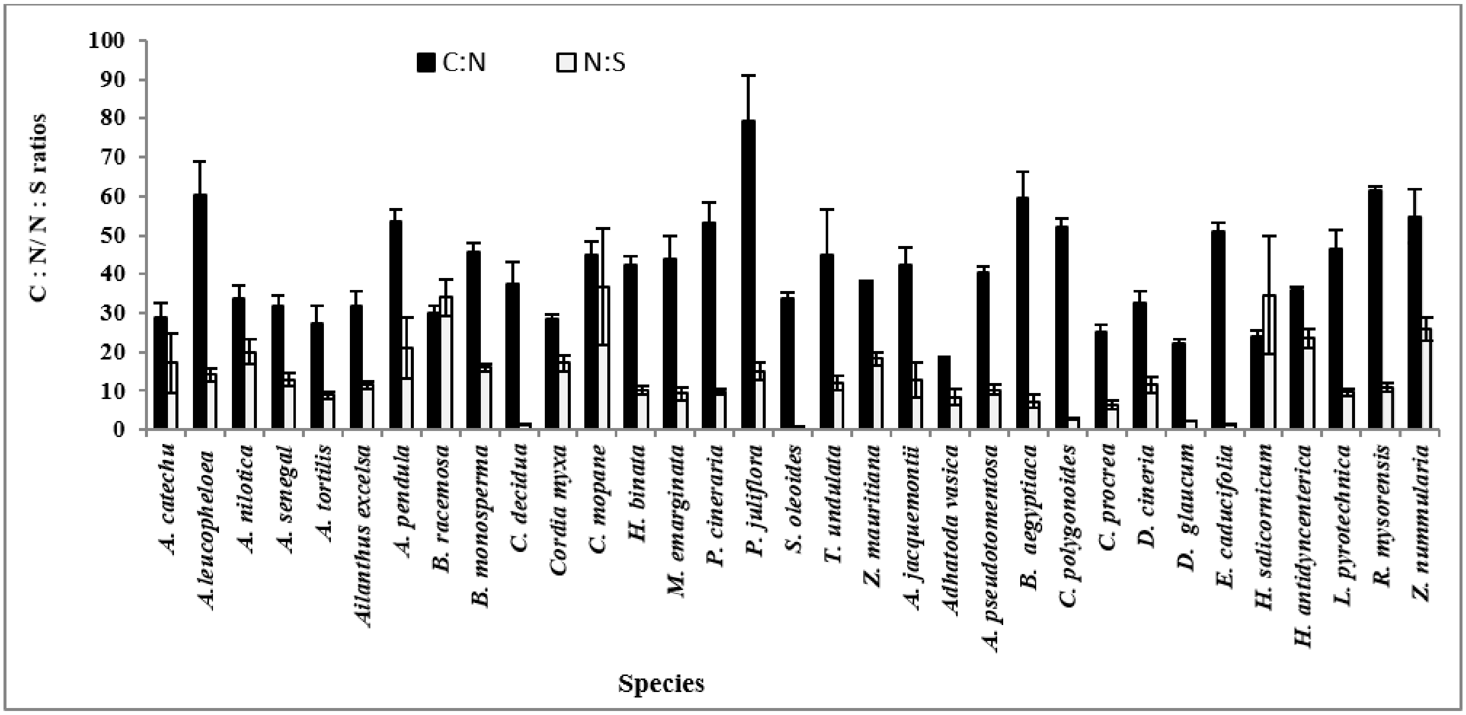

Figure 5

Carbon to nitrogen and nitrogen to sulfur ratios in some species of trees and shrubs Rajasthan, India

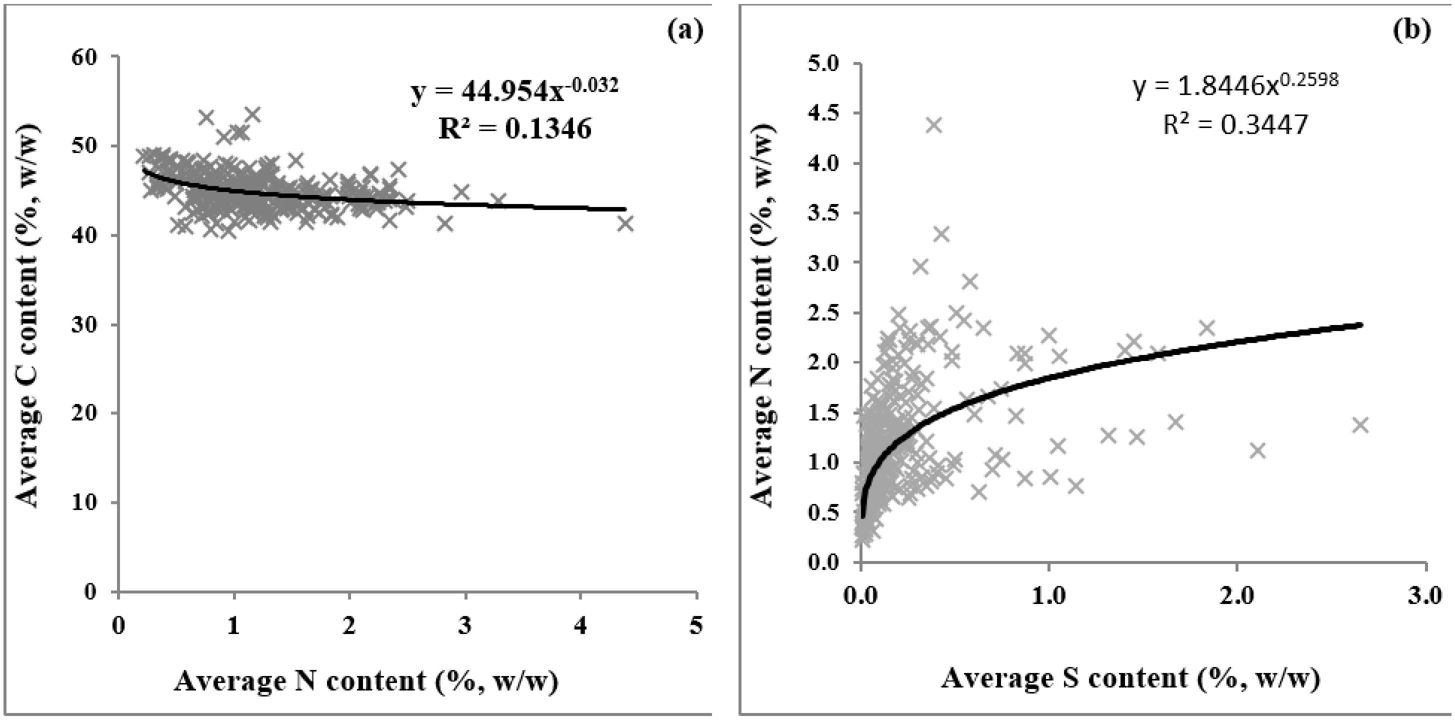

Figure 6

Relationship between average concentrations of carbon and nitrogen (a) and nitrogen and sulfur (b) in plant system across the species and plant organs