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Roadside vegetation diversity of Jodhpur district and its role in carbon sequestration and climate change mitigation

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Abstract
Roads are anthropogenicaly constructed ecosystem which support varying vegetation either planted or grown naturally and play an important role in carbon sequestration and climate change mitigation. A study was conducted to monitor vegetation diversity and their relations to carbon storage in both soil and vegetation growing the along roadsides in forty five villages covering nine forest ranges in Jodhpur district. A total number of 140 plant species belonging to 35 families were recorded during field study. Most of them are ephemerals and annuals. We observed significant positive relations between species diversity and species richness with both aboveground and belowground biomass. The enhanced species diversity and species richness of tree through plantation and sapling, shrubs and herbs through regeneration had positive correlation (P<0.05) with carbon storage in both biomass and soils. However, high diversity in topography, soils and better rainfall in Mandor and Osian enhanced, whereas high soil pH in Baap and Luni negatively affected plant diversity and carbon storage. Intensive farming and anthropogenic pressure in Bilara area affected carbon storage. Conclusively, effects of vegetation, nutrient status, texture, history of the site had important bearing on carbon storage. Roadside vegetation diversity played significant role in sequestering carbon in woody biomass as well as in soil. There is need to manage this man made ecosystem judiciously to enhance carbon sequestration and help mitigate climate change.
Key words: Species diversity; Xerophytes; Biomass; Carbon stock.

Introduction

The increasing atmospheric greenhouse gases including carbon dioxide (CO_2) are contributing to global warming. This emphasises to keep on searching the opportunities for reducing the increasing concentrations of these gases. Growing vegetation is one such method of capturing and storing CO_2 in both vegetation and soils in different land use systems (Lavelle 2014). There is considerable interest to increase carbon storage in terrestrial vegetation in different land-use like afforestation of wastelands, roadside and degraded pasturelands. Vegetations growing along roadside perform ecological function not only on reducing pollution load but also sequester carbon and help mitigate climate change (Da Silva et al. 2010). Roadsides provide a substantial area beyond the paved or travelled ways extending up to field boundaries and adjacent private properties with the roads (Oliveira 2005). Because of varying species and their composition roadside is one land use that can be used as a carbon sink together with their role in performing various ecological functions like reducing air pollution and improving quality of urban environment (Ament and Begley 2014). The plant species richness and some functional traits of the plant accelerate building-up of new carbon pools throughout the soil profile with increasing age, where effects of plant diversity was positive in mitigating soil carbon losses in deeper horizons (Steinbeiss et al. 2008). This indicates that higher diversity lead to higher soil carbon sequestration in the long-term emphasising the role of biodiversity conservation in climate change mitigation.

Because of a close relationship between biodiversity and climate change, which are important issues since recent few decades, one require to understand the vegetation structure and their relations with the carbon stored in the vegetation as well as soils (Alkemade et al. 2011; SCBD 2009). Further, environmental programs could not sustain without knowing the status of vegetation diversity of the area. Depending upon the types of species and their composition different land uses differ in carbon storage potential as well as their ecological functions (Hicks et al. 2014). For example healthier and more diverse area with more dense shrub and tree cover are associated with greater aboveground carbon as well as soil carbon (Eldridge and Wilson 2002). Vegetation particularly trees have ability to enhance the resilience of the roadsides ecosystem for coping with the adverse effects of climate change and together with developing greeneries, absorb more carbon (Murthy et al. 2013) and make the road an effective way to become the area more comfortable (Neema and Jahan 2014). For proper management of roadsides there need to understand the ecological relationship of road side vegetation and their role in carbon storage vegetation of an area (Božena 2010).

Therefore, this study was conducted to evaluate vegetation diversity and carbon sequestration along roadside in Jodhpur district, Rajasthan in hot arid zone of India. Some relationships between plant diversity and carbon stock have also been worked out for their use in designing road side afforestations.

Material and methods

Description of the site

The areas under present investigations are located in Jodhpur district of Rajasthan, India. These are situated between 26°03' and 27°34' North latitude and between 71°58' and 73°44' East longitude (Fig. 1). Altitude varies from 171 to 334 m from sea level. The climate is arid characterises by extreme of temperature, uncertain rainfall, high potential of evapotranspiration and strong winds. The soils are sandy to sandy loam in texture, whereas soil depth varies according to physiographic conditions of the area (http://www.indianetzone.com/45/geography_jodhpur_district.htm). Presence of hard pan is a common feature in the region. Soils of Balesar, Shergarh and Osian are dominated by dune sands, whereas the soils of Luni and Baap ranges showed high pH and electrical conductivity resulting in high percentage of soluble salts, which is an important characteristic of hot desert Maximum temperature rises up to 51°C during summer, whereas minimum temperature drop down to freezing point during winter season (Poonia and Rao 2013). The annual rainfall varied from 58 mm to 800 mm during 1960 to 2012 (Poonia and Rao 2013). Physiography of the study area is plain with occasional hills and rock out crops interspersed with sand dunes in some parts of the district. The vegetation of area is xerophytic, where most of the plant species are spiny having well developed root system and smaller in leaf size (Annex 1).

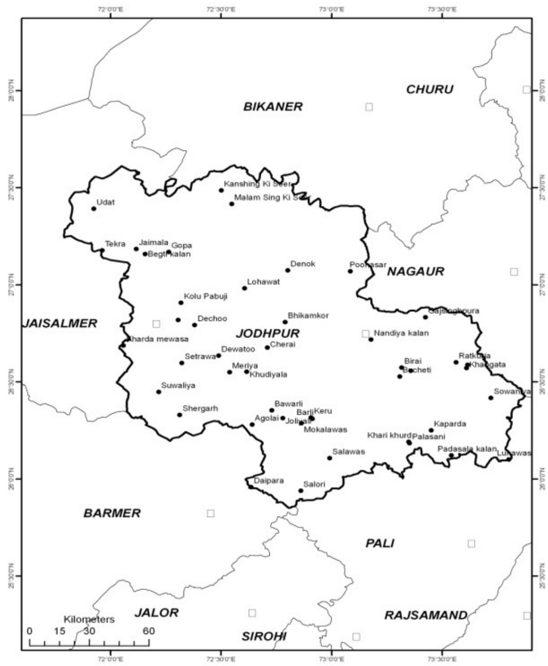

Figure 1. Location of the study area.

Study design and vegetation study

Whole district is divided into 9 forest ranges. Five villages were randomly selected in each 9 forest ranges making a total of 45 villages in the district in 2011. Depending upon the availability of different types of roads, viz. National Highway (NH), State Highway (SH) and Village Roads (VR) were considered in all selected 45 villages. A total 45 quadrates of 100 meter long and width depending on the available area between paved or travelled ways and the private field boundaries were laid out along the roads. In this seven quadrates were identified along National Highways (NH), seven along State Highway (SH) and 31 along the village roads on both the sides of the road.

All the trees with diameter at breast height (DBH) >10cm were measured for DBH and height in the plots. Shrubs and tree saplings were measured for collar diameter and height in two plots of 3 m x 3m plots in the above-mentioned plots. In case of multiple stem in the shrubs, individual tillers were measured and converted to a single value using equation $D=\sqrt{d_1^2+d_2^2+d_3^2+.......d_n^2}$ (Chojnacky 1999). Here D in collar diameter and d is diameter of individual tiller. Herbaceous vegetations were studied in a nested plot of 1m x 1m size laid in the shrubs plots. These species were counted manually and number and population of these herbaceous species were recorded. Plants were identified as per taxonomical classification using standard literature (Shetty and Singh 1993; Bhandari 1990).

Data calculation and biomass and carbon estimation

For calculation diversity indices MS Excel and SPSS 8.0 software were used. Various diversity variables like species richness, Shanon-Weiner diversity index, Simpson's species dominance and species evenness were calculated following standard literatures (Magurran 1988; Shannon and Weiner 1963; Simpson 1949; Pielou 1966). Dry biomass estimation was done based on diameter at breast height (DBH) for trees and collar diameter for tree saplings and shrubs using common regression equations (Table 1), developed by Singh (2014). Herbaceous biomass was estimated after clipping the vegetation from ground (fresh biomass) and drying the fresh biomass in a hot air oven at 65°C. Carbon stock estimation was done by multiplying the dry biomass with a factor of 0.447 (Singh 2014).

Statistical analysis

A one way analysis of variance (ANOVA) followed by post-hoc test were performed. Pearson correlation coefficient was also calculated to correlate the different parameters by using SPSS8.0 package. The level of significant was set at 0.05.

Table 1. Different regression equations used in predicting standing biomass of different plant habits.

Equation	Plant habit	Equations
1	Shrubs	AGDB (kg) = $1.422873 - 0.909824*D + 0.199237*D^2$
2		RDB (kg) = $1.221440 – 0.76480*D + 0.138231*D^2$
3	*Euphorbia* spp.	AGDB (kg) = $-7.743361 + 19.058617*CD - 2.861409*CD^2$
4		RDB (kg) $0.130452+0.768141*CD$
5	Trees	AGDB (kg) = $0.181494261*D^{2.058650773}$
6		RDB (kg) = $0.084773863* D^{2.028825779}$
7	Tree saplings	AGDB (kg) = $0.035391472* D^{3.087807162}$
8		RDB (kg) = $0.026583624* D^{2.699255524}$

AGDB = above ground dry biomass, RDB = root dry biomass, D = diameter at breast height, CD = collar diameter.

Results

Species composition and diversity

A total number of 140 plant species belonging to 35 families were recorded during field study. These species are grass (28), herbs (68), twinner (2), trailer (2), undershrubs (3), sedge (4), climber/lianas (6), shrubs (13) and trees (14) species (Fig. 2; Annex 1). Dominant family was Poaceae with 28 plant species followed by family Asteraceae with 12 plants. Only one species was recorded in the family's Brassicaceae, Celastraceace, Commelinaceae, Ehretiaceae, Meliaceae, Menispermaceae, Polygalaceae, Portulacaceae, Salvadoraceae and Simarubiaceae, Verbenaceae (Fig. 3A-C).

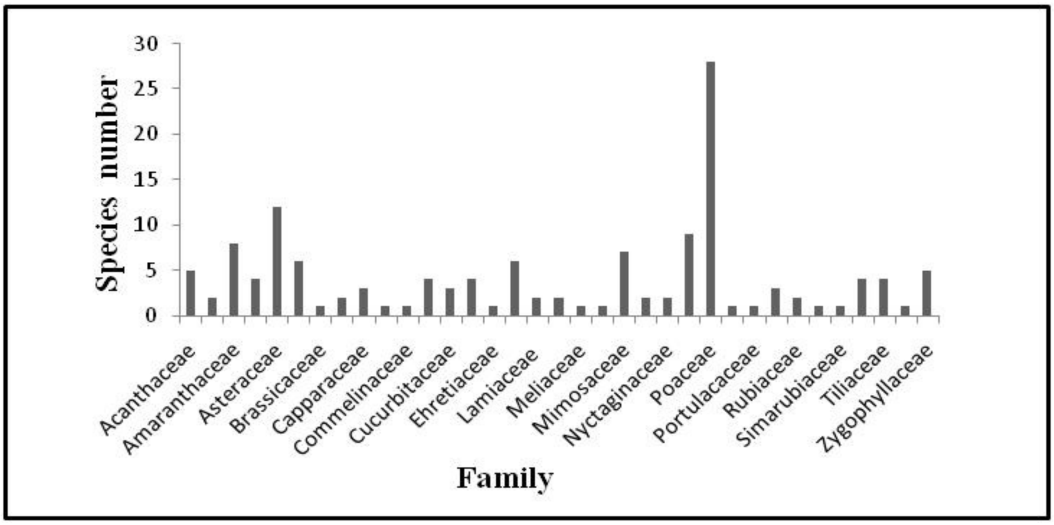

Figure 2. Number of species belonging to different families.

Figure 3. (A) Dominant tree species: *Acacia tortilis*, (B) Shrub: *Calotropis procera*, (C) Undershrub & grass: *Tephrosia purpurea* and *Aristida funiculate*.

Tree population and diversity

Tree population and diversity did not vary (P>0.05) between forest ranges. Both these variables were highest in Mandor and lowest in Baap (Table 2). This variation was due to plantation, which was very limited in Baap range. Tree species richness was highest (P=0.05) in Luni and lowest in Baap, whereas Simpson's reciprocal index was highest in Mandor and lowest in Baap range. Evenness of tree species was highest (P>0.05) in Mandor and lowest in Bhopalgarh.

Sapling population and diversity

Tree Sapling population differed (P<0.01) between forest ranges, where it was highest in Luni and lowest in Baap (Table 3). Sapling diversity and Simpson's reciprocal index did not differ (P>0.05) between ranges, but species evenness was highest (P=0.056) in Luni range.

Shrub population and diversity

Shrub population varied significantly (P<0.01) between roadside of forest ranges. The highest population of shrub was observed along roadside of Mandor range while lowest in Bilara forest range (Table 4). Shrub diversity variables did not vary significantly (P>0.05) between forest ranges. Species diversity, species richness and Simpson's reciprocal index were highest in Balesar forest range and lowest in Baap forest range. Species evenness was highest in Mandor (0.72) and lowest in Phalodi range (0.22).

Herbaceous population and diversity

There were no difference (P>0.05) in roadsides herbaceous population between different forest ranges. However, it was highest along roadside of Balesar and Mandor ranges (Table 5). Species diversity, Simpsons's reciprocal index and species evenness did not differ but former two indices were higher in Phalodi and the latter one was higher in Baap as compared to the other ranges. However, species richness varied significantly (P<0.01) and it highest in Mandor and lowest in Baap range.

Live and dead biomass density

Above ground as well as below ground tree standing dry biomass density varied (P=0.056) between forest ranges. Densities of both these biomasses were highest in Mandor and lowest in Baap forest range. The total biomass (above + below) ranged between 19.86 Mg ha^{-1} on roadsides in Mandor and 3.90 Mg ha^{-1} in Baap range. However, biomass of tree sapling in all components ranged ($P<0.05$) from 202.55 kg ha^{-1} along roadsides in Bilara to 22.21 kg ha^{-1} in Shergarh (Table 6). Above ground, below ground and total biomass densities of shrubs were highest in Balesar and lowest in Bilara forest range (Table 6). Herbaceous biomass also varied significantly ($P<0.05$) being highest (1.02 Mg ha^{-1}) along the roadside of Luni and lowest of 0.52 Mg ha^{-1} in Phalodi range. Combined (above-ground and below ground biomass density all plant habit + dead biomass) biomass varied ($P<0.05$) significantly along the roadsides of different ranges (Table 7).

All biomasses were highest in Mandor, except dead biomass, which was highest in Luni range. Lowest values were observed in Bilara range, except sapling and herbaceous biomass, which were lowest in Phalodi range, whereas sapling biomass was lowest in Shergarh range.

Table 2. Diversity indices of trees along the roadside in different forest range in Jodhpur district of Rajasthan, India.

Range	Population	Diversity	Richness	Simpson's reciprocal index	Evenness
Baap	31.67±9.77	0.38±0.16	1.40±0.40	1.29±0.49	0.54±0.23
Balesar	95.93±26.94	0.90±0.19	3.60±0.81	2.28±0.39	0.59±0.16
Bhopalgarh	97.73±28.88	0.49±0.25	2.20±0.58	1.69±0.28	0.44±0.20
Bilara	89.57±21.60	0.58±0.18	2.20±0.37	1.75±0.23	0.45±0.20
Luni	132.42±18.39	0.90±0.25	3.80±0.97	2.41±0.31	0.73±0.10
Mandor	147.22±43.31	1.03±0.12	3.60±0.40	2.50±0.38	0.81±0.05
Osian	55.75±15.97	0.45±0.23	2.00±0.55	1.61±0.61	0.47±0.20
Phalodi	48.79±9.50	0.44±0.18	1.80±0.37	1.56±0.71	0.54±0.22
Shergarh	107.63±50.15	0.81±0.25	3.00±0.63	2.40±0.00	0.74±0.14
One way ANOVA					
F-value	1.837	1.429	2.207	1.031	0.622
P-value	0.102	0.218	0.050	0.431	0.753

Values are mean ± SE of replications.

Table 3. Diversity variables trees sapling along roadsides in Jodhpur district of Rajasthan.

Range	Population	Diversity	Richness	Simpson's reciprocal index	Evenness
Baap	49.55±26.33	0.28±0.17	1.00±0.45	1.00±0.44	0.40±0.24
Balesar	96.05±33.28	0.31±0.20	1.60±0.40	1.42±0.29	0.34±0.21
Bhopalgarh	72.73±42.46	0.08±0.08	1.00±0.32	0.86±0.22	0.12±0.12
Bilara	418.37±144.92	0.46±0.14	2.00±0.32	1.55±0.20	0.58±0.17
Luni	463.64±162.44	0.48±0.12	1.80±0.20	1.57±0.17	0.69±0.18
Mandor	100.89±32.23	0.00±0.00	1.00±0.00	1.00±0.00	-
Osian	82.88±29.57	0.19±0.19	1.20±0.49	1.09±0.39	0.18±0.18
Phalodi	62.42±24.8	0.00±0.00	0.80±0.20	0.80±0.20	-
Shergarh	57.85±20.43	0.14±0.14	1.20±0.20	1.20±0.20	0.20±0.20
One way ANOVA					
F-value	4.424	1.735	1.674	1.288	2.149
P-value	0.001	0.124	1.39	0.280	0.056

Values are mean ± SE of 5 village replications.

Table 4. Diversity of shrub species along the roadside in different forest ranges in Jodhpur district of Rajasthan, India.

Range	Population	Diversity	Richness	Simpson's reciprocal index	Evenness
Baap	391.82 (±110.99)	0.15±0.11	1.40±0.24	1.13±0.11	0.22±0.15
Balesar	904.95±294.15	0.87±0.26	3.40±0.68	2.44±0.57	0.63±0.17
Bhopalgarh	150±54.19	0.30±0.19	1.60±0.40	1.40±0.26	0.34±0.21
Bilara	19.07±5.60	0.35±0.23	1.40±0.51	1.36±0.50	0.38±0.24
Luni	197.58±64.04	0.55±0.26	2.40±0.68	1.82±0.45	0.46±0.19
Mandor	1096.17±299.21	0.86±0.16	3.40±0.40	2.24±0.46	0.72±0.08
Osian	265.15±97.63	0.61±0.29	2.60±0.81	1.96±0.58	0.50±0.21
Phalodi	97.12±57.01	0.23±0.23	1.80±0.80	1.33±0.33	0.14±0.14
Shergarh	340.72±106.96	0.72±0.23	3.00±0.63	1.97±0.36	0.59±0.18
One way ANOVA					
F-value	5.632	1.467	1.850	1.218	1.108
P-value	0.000	0.204	0.100	0.316	0.381

Values are mean ± SE of replications.

Table 5. Diversity indices of herbaceous species along the roadsides in different forest ranges in Jodhpur district of Rajasthan, India.

Range	Population	Diversity	Richness	Simpson's reciprocal index	Evenness
Baap	55.00±5.39	1.94±0.09	10.20±1.02	5.81±0.69	0.84±0.03
Balesar	68.10±5.53	2.06±0.08	14.80±1.24	5.98±0.52	0.77±0.02
Bhopalgarh	58.40±5.69	1.98±0.06	14.40±1.12	5.31±0.45	0.75±0.02
Bilara	62.10±5.95	2.07±0.10	14.6±0.98	6.02±0.72	0.77±0.02
Luni	67.00±5.93	2.16±0.07	15.40±1.36	6.72±0.68	0.80±0.03
Mandor	68.00±2.97	1.91±0.08	13.20±0.97	5.19±0.57	0.75±0.03
Osian	52.40±2.90	2.20±0.07	15.00±0.89	7.01±0.46	0.81±0.02
Phalodi	64.45±3.25	1.91±0.20	10.40±1.12	5.99±0.97	0.82±0.05
Shergarh	55.55±2.56	1.97±0.11	12.00±0.89	6.15±0.77	0.80±0.03
One way ANOVA					
F-value	1.683	1.075	3.459	0.634	1.236
P-value	0.136	0.402	0.005	0.744	0.307

Values are mean ± SE of replication.

Table 6. Dry biomasses of tree, shrub, herbaceous biomass and sapling biomass along the roadside of forest range in Jodhpur district.

Range	------- Tree ($Mg\ ha^{-1}$) -------		------- Sapling ($kg\ ha^{-1}$) -------		------- Shrub ($Mg\ ha^{-1}$) -------		Herb ($Mg\ ha^{-1}$)
	Above	Below	Above	Above	Above	below	Above
Baap	2.75±1.84	1.15±0.76	19.10±10.24	10.61±5.68	1.50±0.51	1.01±0.37	0.60±0.03
Balesar	7.49±1.47	3.17±0.62	45.11±20.11	24.08±10.36	6.99±2.51	4.80±1.75	0.70±0.12
Bhopalgarh	7.57±3.49	3.2±1.46	46.47±35.25	24.01±17.78	1.06±0.54	0.73±0.37	0.73±0.09
Bilara	3.00±1.40	1.28±0.59	130.37±37.98	72.18±19.03	0.05±0.03	0.03±0.02	0.93±0.15
Luni	8.64±3.90	3.68±1.65	113.06±45.86	66.06±25.91	0.52±0.17	0.33±0.12	1.02±0.14
Mandor	13.99±4.52	5.88±1.89	40.14±16.40	21.94±8.75	5.32±1.67	3.54±1.16	0.77±0.10
Osian	2.80±1.36	1.19±0.57	32.56±13.41	17.97±7.26	3.15±1.18	2.16±0.81	0.67±0.06
Phalodi	3.12±1.49	1.31±0.61	30.48±17.04	16.2±8.70	0.18±0.12	0.12±0.08	0.52±0.04
Shergarh	4.90±0.780	2.10±0.33	13.98±6.03	8.23±3.48	1.19±0.13	0.78±0.11	0.66±0.13
One way ANOVA							
F-value	2.151	2.165	2.493	2.897	4.844	4.844	2.280
P-value	0.056	0.054	0.029	0.013	0.000	0.000	0.044

Values are mean ± SE of 5 village replications.

Table 7. Total biomass ($Mg\ ha^{-1}$) both live and dead recorded along roadsides in different ranges in Jodhpur districts of Rajasthan, India.

Range	Above ground	Below ground	Total live	Dead biomass	Total biomass
Baap	4.12±1.72	1.67±0.68	5.78±2.40	0.04±0.02	5.82±2.41
Balesar	11.73±1.62	5.60±0.97	17.33±2.55	0.41±0.19	17.74±2.63
Bhopalgarh	8.87±3.51	3.59±1.47	12.47±4.98	0.66±0.41	13.13±5.30
Bilara	4.08±1.54	1.37±0.60	5.45±2.14	0.22±0.06	5.66±2.12
Luni	10.03±4.01	3.91±1.71	13.94±5.72	1.70±0.69	15.64±5.87
Mandor	17.46±4.86	7.67±2.14	25.13±6.99	0.43±0.11	25.56±7.09
Osian	5.08±0.84	2.28±0.20	7.36±1.04	0.65±0.33	8.01±0.94
Phalodi	3.75±1.45	1.38±0.60	5.14±2.04	0.09±0.02	5.23±2.03
Shergarh	6.17±0.69	2.49±0.31	8.67±0.99	0.54±0.22	9.21±1.13
One way ANOVA					
F value	3.001	3.456	3.137	2.576	3.126
P value	0.011	0.005	0.009	0.025	0.009

Values are mean ± SE of 5 village replications.

Live and dead carbon density

Carbon densities in both above and below ground biomasses of trees approached significant level (*P*=0.055), but these values differed significantly (*P*<0.05) for tree saplings and shrubs as well as herbaceous vegetation (Table 8). Highest carbon densities for both above and below ground in trees were along the roadsides in Mandor, tree sapling in Bilara, herabaceous vegetation in Luni and in shrubs in Balesar ranges. Carbon density in dead material also varied (*P*<0.05) between different ranges, where it ranged between 0.76 $Mg\ ha^{-1}$ in Luni and 0.02 $Mg\ ha^{-1}$ in Baap range. Overall carbon density in plant biomass varied (*P*<0.01) along the roadside of different ranges, where it ranged from 11.43 $Mg\ ha^{-1}$ in Mandor to 2.34 $Mg\ ha^{-1}$ in Phalodi range.

Carbon density in soils

Density of soil organic carbon (0-30 cm, 31-60, 61-100 cm and cumulative in 0-100 cm soil layers) varied (*P*<0.05) among the roadsides of different forest ranges. It was highest in deeper (61-100 cm) soil layer in all ranges, except Bilara, where it was highest in 31-60 cm soil layer. It ranged from 2.32 to 4.64 $Mg\ ha^{-1}$ in 0-30 cm, 2.42 to 5.93 $Mg\ ha^{-1}$ in 31-60 cm and 2.15 to 6.97 $Mg\ ha^{-1}$ in 61-90 cm soil layers. SOC density in 0-100 cm soil layer ranged between 6.95 $Mg\ ha^{-1}$ in Bilara and 17.53 in Balesar range with an average value of 12.63 $Mg\ ha^{-1}$ for the roadside SOC of Jodhpur district (Table 9).

Correlations among different variables

Tree population, richness and diversity showed significant correlation (r=0.315-0.570, *P*<0.05) to their above ground, below ground and total biomass as well as carbon stock. Simpson's reciprocal index and evenness of tree species have no correlations with live carbon of tree. Sapling population, richness, evenness and diversity were also correlated (r=0.403-0.828, *P*<0.05) to their carbon stock, while Simpson's reciprocal index did not correlate. Shrub population richness diversity and evenness had positive correlation (r= 0.325-0.761, *P* <0.05) to their carbon stock. In herbaceous vegetation, species richness have positive significant correlation (r=0.442, *P*<0.05) with their carbon stock. Soil organic carbon density in 0-30 and and 61-100 cm soil layers were correlated significantly to only shrub population, shrub richness and shrub diversity (Table 10).

Table 8. Carbon densities of roadside tree and tree, shrub and herbaceous carbon stock ($Mg\ ha^{-1}$) and saplings carbon stock ($kg\ ha^{-1}$).

Range	------ Tree C ------ ($Mg\ ha^{-1}$)		-------- Sapling C -------- ($kg\ ha^{-1}$)		------- Shrub C ------- ($Mg\ ha^{-1}$)		Herb C ($Mg\ ha^{-1}$)	Dead C ($Mg\ ha^{-1}$)	Total C ($Mg\ ha^{-1}$)
	Above	Below	Above	Below	Above	Below	Above		
Baap	1.23±0.82	0.51±0.34	8.54±4.57	4.741±2.54	0.34±0.11	0.23±0.08	0.27±0.01	0.02±0.01	2.60±1.08
Balesar	3.35±0.66	1.42±0.28	20.16±8.99	10.76±4.63	1.56±0.56	1.07±0.39	0.31±0.05	0.18±0.08	7.93±1.18
Bhopalgarh	3.38±1.56	1.43±0.65	20.77±15.76	10.73±7.95	0.23±0.12	0.16±0.08	0.33±0.04	0.30±0.18	5.87±2.37
Bilara	1.34±0.63	0.57±0.26	58.27±16.98	32.27±8.51	0.01±0.00	0.01±0.00	0.42±0.07	0.10±0.03	2.53±0.95
Luni	3.86±1.74	1.65±0.74	50.54±20.50	29.53±11.58	0.11±0.04	0.07±0.03	0.46±0.06	0.76±0.31	6.99±2.62
Mandor	6.25±2.02	2.63±0.84	17.94±7.33	9.81±3.91	1.19±0.37	0.79±0.26	0.35±0.04	0.19±0.05	11.43±3.17
Osian	1.25±0.61	0.53±0.26	14.55±5.99	8.03±3.25	0.70±0.26	0.48±0.18	0.30±0.03	0.29±0.15	3.58±0.42
Phalodi	1.39±0.67	0.59±0.27	13.63±7.62	7.24±3.89	0.04±0.03	0.03±0.02	0.23±0.02	0.04±0.01	2.34±0.91
Shergarh	2.19±0.35	0.94±0.15	6.25±2.70	3.68±1.55	0.26±0.03	0.17±0.02	0.30±0.06	0.24±0.10	4.12±0.50
One way ANOVA									
F-value	2.151	2.170	2.493	2.897	4.864	4.667	2.317	2.579	3.127
P-value	0.056	0.054	0.029	0.013	0.000	0.001	0.041	0.025	0.009

Values are mean ± SE of 5 village replications.

Table 9. Soil organic carbon (SOC) density (Mg ha^{-1}) in different soil layers along roadsides in different ranges in Jodhpur district of Rajasthan, India.

Range	Soil layer (cm)			Cumulative up to 1 m
	0-30	31-60	61-100	0-100
Baap	3.22±0.68	3.48±0.84	3.48±1.00	10.19±2.33
Balesar	4.64±0.28	5.93±0.53	6.97±0.40	17.53±0.77
Bhopalgarh	3.28±0.29	4.40±0.91	5.51±1.22	13.19±2.29
Bilara	2.38±0.57	2.42±0.52	2.15±0.43	6.95±1.24
Luni	3.56±0.22	3.49±0.90	3.64±1.21	10.69±2.25
Mandor	3.13±0.15	4.55±0.30	6.29±1.28	13.97±1.53
Osian	3.41±0.36	5.06±0.65	6.52±0.23	15.00±0.82
Phalodi	2.91±0.67	4.06±0.87	4.95±1.27	11.92±2.51
Shergarh	2.32±0.14	5.21±0.81	6.72±0.28	14.25±1.13
One way ANOVA				
F-value	2.628	2.107	3.396	3.042
P-value	0.022	0.061	0.005	0.010

Values are mean ±SE of 5 village replications.

Table 10. Correlations of different diversity indices with above ground and below ground carbon stock of tree, tree sapling, shrub and herbs as well as soil carbon density in different soil layers.

Habit	Diversity variable	Live carbon (Mg ha^{-1})			Soil organic carbon density (Mg ha^{-1})		
		AGB	BGB	TGB	0-30 cm	31-60 cm	61-100 cm
Tree	Population	NS	NS	NS	NS	NS	NS
	Richness	0.547**	0.554**	0.549**	NS	NS	NS
	Diversity	0.370*	0.372*	0.371*	NS	NS	NS
Sapling	Population	0.760**	0.836**	0.790**	NS	NS	NS
	Richness	0.524**	0.512**	0.511**	NS	NS	NS
	Diversity	0.417**	0.414**	0.407**	NS	NS	NS
Shrub	Population	0.760**	0.752**	0.757**	0.327*	NS	0.448**
	Richness	0.469**	0.462**	0.466**	0.378*	NS	0.436**
	Diversity	0.422**	0.416**	0.419**	0.336*	NS	0.373*
Herb	Richness	0.444**	-	-	NS	NS	NS

NS no significant at $P<0.05$, * significant at $P<0.05$, ** significant at $P<0.01$.

Discussion

Roadside plant diversity

Understanding species diversity, composition and development of plant communities are important in maintaining sustainability and function of the ecosystems (Chen et al. 2006). Greater number of herbaceous species as compared to other plant habits appeared to be the effects of soil and soil water influenced by rainfall pattern. The highest number of ephemerals as compared to number of trees and shrubs in the region is indicative of low rainfall confined to limited period of a year. Number of species as well as species diversity is low in the study similar to the other study carried out in arid environments (Fearnehough et al. 1998; Saiz et al. 2014). Though arid regions are more suitable for shrubs, but relatively greater number of tree species as compared to the shrub species appeared to be due to introduction of tree species under plantation along the roads. The study done by Sera (2010) along different types of roads recorded 235 plant species from 38 families. Most of the recorded species observed along secondary road (127 species) followed by motorway including median stripes (34 species), whereas 74 species found growing along both road types.

Significant variations in the population and diversity indices of trees, saplings, shrubs and herbaceous vegetation along the roadsides of different forest ranges indicated a combined effects human interference as well as variation in soil and environmental conditions. Fonge et al. (2011) also observed variations in colonization and vegetation establishment on three lava flows in Cameroon influenced by rainfall and soil organic carbon. Roadside plantation of different tree species and their establishment was favoured in Mandor range resulting in increased tree diversity and growth. Highest (P=0.05) tree and herbaceous species richness, and sapling diversity and its Simpson's reciprocal index in Luni range was due to better resource availability favouring tree regeneration that influenced composition and diversity of the sapling.

Kumar (1996) also observed strong correlation of vegetation groupings with soil texture and soil moisture holding capacity. Relatively high species richness and diversity in Mandore range appeared also related to a diverse topography and soil conditions (Fonge et al. 2011; Zhang et al. 2013). In contrast harsh edaphic and climatic conditions in Baap range affected the population and diversity of all plant groups under study. Sandy soils with relatively high aridity in Balesar range appeared favourable for shrub species indicated by highest shrub species diversity, richness and Simpson's reciprocal index. In a study carried out in a part of Barmer district, frequency of occurrence of *Leptadenia pyrotechnica* varied from 19.2% to 64.3%, whereas abundance varied from 5.9 to 195.2 number per hectare in different land uses like agriculture, community and forest lands, whereas frequency of occurrence of tree species was relatively less except for *Prosopis cineraria* and *Tecomella undulata* (Singh 2008). It shows the arid region is much conducive for shrub population as compare with tree which require larger amount of water for their survival. Occurrence of *Leptadenia pyrotechnica* along with *Prosopis cineraria* and *Zizyphus nummularia* in all studied throughout the desert with varying soil conditions indicating its wide adaptability in the region, though *Prosopis cineraria* and *Zizyphus nummularia* are socially acceptable species (Singh et al. 2012).

Roadsides biomass and carbon density

Significant variations in both biomass and carbon densities in above, below ground and total plant live material appeared very much related to population and species diversity indicated by positive correlations ($P<0.05$) between these variables. It is also indicated by the highest values of these biomass/carbon storage variables for trees along the roadsides in Osian, tree sapling and herbaceous vegetation in Manore and in shrubs in Balesar ranges indicating the influence of soil, plant species diversity and climatic conditions (Shankar et al. 2014). Vance-Chalcraft et al. (2010) also observed a unimodal relationship between species richness and above-ground biomass and a positive, linear relationship at mature site. However, crucial role of prior land use on plant diversity and carbon sequestration cannot be ignored.

We observed significant positive correlations of species richness as well as species diversity with respective above-ground and below-ground both biomasses of tree, shrubs and herbaceous vegetation. Highest population of trees along the roadside in Osian resulted in high live carbon stock, because tree contributed highest amount of carbon among the standing live carbon (Conti and Díaz 2012; Singh 2014). Based on a study Potter and Woodall (2014) concluded phylogenetic species clustering and species richness appear as the best biodiversity predictors for above ground biomass on the low-productivity and considered the most important for carbon/biomass management. Relatively high species richness and rocky habitats appeared the cause of greater litter in the range, whereas adversity of environment in Baap negatively affected the growth and biomass and thus total carbon storage (Pan et al. 2013).

Differences in soil organic carbon density in different soil layers between the ranges appeared to be due to variations in soil texture and rainfall pattern. Downward movement of SOC in the sandy soils of the region is the probable cause of greater SOC density in deeper soil layer as compared to the top soil layer (Li et al. 2010). However, Aeolian sand deposits on the herbaceous vegetation and its mineralization to develop organic matter might also be responsible for low SOC in 0-30 cm soil layer (Fearnehough et al. 1998). However, strong spatial variation in SOC density along the roadsides in different ranges was similar to the plant diversity and composition and indicates the impact of interactions of soil type, plants and environments (Morris et al. 2010; Wang et al. 2011).

Venkanna et al. (2014) also recorded variations in SOC with soil texture and observed a significant correlation between SOC stock and soil nitrogen with annual rainfall. However, heterogeneity due to species or amelioration of soil quality before planting also influenced carbon storage (Anikwe 2010). This is reflected by a variation in SOC density in 0-100 cm soil layer from 6.95 Mg ha^{-1} in Bilara to 17.53 Mg ha^{-1} in Balesar range (Saha et al. 2009). A positive correlation ($P<0.05$) between shrub population, richness, diversity and evenness with the SOC density indicates favourable effects of shrub on soil carbon storage. However, increased anthropogenic activity in Bilara and relatively high soil pH and salinity affecting plant population and diversity had negative effects on carbon storage in Bilara, Luni and Baap ranges. Pan et al. (2013) also observed a significant decrease in soil organic carbon and nitrogen with increasing salinity that were positively correlated to Normalized Difference Vegetation Index (NDVI), soil water, and fine particles (silt+clay) content, but had negative correlations with soil electrical conductivity, and sand content.

Conclusions

Significant spatial variations in the plant diversity and carbon density in both biomass and soil along the roadsides in different forest rages were the effects of topography, soil and environmental conditions. Though a total number of 140 plant species belonging to 35 families were recorded but these are dominated by ephemerals and annuals and were influenced particularly by soil water availability through rainfall during monsoon season. Introduction of trees along the roadsides through plantation not only showed positive influence on carbon accumulation in tree and herbaceous biomass but also on soil carbon storage.

However, shrubs observed more beneficial on soil carbon storage particularly in more arid conditions like Balesar range. While Mandor, Osian, Falodi and Balesar showed better environment for plant diversity and growth, poor edaphic conditions in Baap and Luni negatively affected plant diversity and carbon storage. Likewise intensive farming and anthropogenic pressure in Bilara area resulted in low plant diversity and carbon accumulation in biomass.

This study indicates that local effects like vegetation, nutrient status, texture, history of the site have great influence on carbon accumulation. However, it highlights the importance of roadside vegetation and diversity in enhancing carbon sequestration and if managed judiciously can play an important role in climate change mitigation.

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Supplementary document

Annex 1. Plant species and their habit with family.

S. n°	Species	Habit	Family
1	*Cucumis callosus* (Rottl.) Cogn.	Climber	Cucurbitaceae
2	*Mukia maderaspatana* (L.) M. Roem.	Climber	Cucurbitaceae
3	*Pergularia daemia* (Forsk.) Chiov.	Climber	Asclepiadaceae
4	*Aeluropus lagopoides* (L.) Trin. Ex Thw.	Grass	Poaceae
5	*Aristida adscensionis* L.	Grass	Poaceae
6	*Aristida funiculata* Trin. & Rupr.	Grass	Poaceae
7	*Aristida mutabilis* Trin.& Rupr.	Grass	Poaceae
8	*Brachiaria ramosa* (L.) Stapf.	Grass	Poaceae
9	*Cenchrus biflorus* Roxb.	Grass	Poaceae
10	*Cenchrus ciliaris* L.	Grass	Poaceae
11	*Cenchrus pennisetiformis* Hochst. & Steud.	Grass	Poaceae
12	*Cenchrus prieurii* (Kunth) Maire	Grass	Poaceae
13	*Cenchrus setigerus* Vahl.	Grass	Poaceae
14	*Chloris barbata* Sw.	Grass	Poaceae
15	*Dactyloctenium aegyptium* (L.) Willd.	Grass	Poaceae
16	*Dactyloctenium scindicum* Boiss.	Grass	Poaceae
17	*Desmostachya bipinnata* (L.) Stapf.	Grass	Poaceae
18	*Digitaria cilliari*s (Retz.) Koel.	Grass	Poaceae
19	*Echinochloa colona* (L.) Link	Grass	Poaceae
20	*Enneapogon schimperanus* (Hochst. ex A. Rich.) Renvoize	Grass	Poaceae
21	*Eragrostis ciliaris* (Linn.) R.Br.	Grass	Poaceae
22	*Eragrostis minor* Host.	Grass	Poaceae
23	*Eragrostis tremula* (Lam.) Hochst. ex Steud.	Grass	Poaceae
24	*Eragrostis viscosa* (Retz.) Trin.	Grass	Poaceae
25	*Melanocenchris jacquemontii* Jaub. & Spach	Grass	Poaceae
26	*Ochthochloa compressa* (Forssk.) Hilu.	Grass	Poaceae
27	*Oligochaeta ramosa* (Roxb.) Wagenitz	Grass	Poaceae
28	*Panicum antidotale* Retz.	Grass	Poaceae
29	*Sporobolus tenuissimus* (Schrank) O. Kntze.	Grass	Poaceae
30	*Tetrapogon tenellus* (Koen. ex Roxb.) Chiov.	Grass	Poaceae
31	*Tragus roxburghii* Panigrahi	Grass	Poaceae
32	*Achyranthes aspera* L.	Herb	Amaranthaceae
33	*Amaranthus spinosus* L.	Herb	Amaranthaceae
34	*Amaranthus viridis* L.	Herb	Amaranthaceae
35	*Arnebia hispidissima* (Lehm.) DC.	Herb	Boraginaceae
36	*Barleria acanthoides* Vahl.	Herb	Acanthaceae
37	*Blepharis sindica* Stocks ex T. Anders.	Herb	Acanthaceae
38	*Blumea obliqua* (L.) Druce	Herb	Asteraceae
39	*Boerhaavia diffusa* L.	Herb	Nyctaginaceae
40	*Boerhavia erecta* L.	Herb	Nyctaginaceae
41	*Borreria articularis* (L.F) F.N.. Willams	Herb	Rubiaceae
42	*Cassia angustifolia* Vahl.	Herb	Caesalpiniaceae
43	*Celosia argentea* L.	Herb	Amaranthaceae
44	*Cleome viscosa* L.	Herb	Capparaceae
45	*Commelina benghalensis* L.	Herb	Commelinaceae
46	*Corchorus depressus* (L.) Stocks	Herb	Tiliaceae
47	*Corchorus olitorius* L.	Herb	Tiliaceae
48	*Corchorus tridens* L.	Herb	Tiliaceae
49	*Cressa cretica* L.	Herb	Convolvulaceae
50	*Crotalaria medicaginea* Lam.	Herb	Papilionaceae
51	*Dicoma tomentosa* (Koenig ex Willd.) Henr.	Herb	Asteraceae
52	*Digera muricata* (L.) Mart.	Herb	Amaranthaceae
53	*Echinops echinatus* Roxb	Herb	Asteraceae
54	*Eclipta alba* (L.) Hassk.	Herb	Asteraceae
55	*Emilia sonchifolia* (L.) DC.	Herb	Asteraceae
56	*Euphorbia chamaesyce* L.	Herb	Euphorbiaceae
57	*Euphorbia granulata* Forssk.	Herb	Euphorbiaceae
58	*Euphorbia hirta* L	Herb	Euphorbiaceae
59	*Fagonia indica* Burm. f.	Herb	Zygophyllaceae
60	*Fagonia schweinfurthii* (Hadidi) Hadidi	Herb	Zygophyllaceae
61	*Farsetia hamiltonii* Royle	Herb	Brassicaceae
62	*Gisekia Pharnaceoides* L.	Herb	Molluginaceae
63	*Heliotropium curassavicum* L.	Herb	Boraginaceae
64	*Heliotropium marifolium* Retz.	Herb	Boraginaceae
65	*Heliotropium subulatum* (Hochst. ex DC.) Vatke	Herb	Boraginaceae
66	*Indigofera argentea* Burm. f.	Herb	Papilionaceae
67	*Indigofera cordifolia* Heyne ex Roth	Herb	Papilionaceae
68	*Indigofera hochstetteri* Baker.	Herb	Papilionaceae
69	*Indigofera linifolia* (L.f.) Retz.	Herb	Papilionaceae
70	*Indigofera linnaei* Ali	Herb	Papilionaceae
71	*Justicia procumbens* L.	Herb	Acanthaceae
72	*Justicia quinqueangularis* Koenig. ex Roxb.	Herb	Acanthaceae
73	*Kohautia aspera* (Heyne ex Roth) Brem.	Herb	Rubiaceae

Continuation...

S. n°	Species	Habit	Family
74	*Launaea procumbens* (Roxburgh) Ramayya & Rajagopal	Herb	Asteraceae
75	*Launaea resedifolia* (L.) Kuntze	Herb	Asteraceae
76	*Leucas cephalotes* (Koen. ex Roth) Spreng.	Herb	Lamiaceae
77	*Mollugo cerviana* (L.) Seringe	Herb	Molluginaceae
78	*Ocimum americanum* L.	Herb	Lamiaceae
79	*Peristrophe paniculata* (Forssk.) Brumm.	Herb	Acanthaceae
80	*Phyllanthus amarus* Schum. & Thonn.	Herb	Euphorbiaceae
81	*Phyllanthus fraternus* Webster	Herb	Euphorbiaceae
82	*Polygala erioptera* DC.	Herb	Polygalaceae
83	*Portulaca oleracea* L.	Herb	Portulacaceae
84	*Pulicaria crispa* (Forssk.) Benth. & Hook. f.	Herb	Asteraceae
85	*Pulicaria wightiana* D. C. Clarke.	Herb	Asteraceae
86	*Pupalia lappacea* (L) Juss.	Herb	Amaranthaceae
87	*Seetzenia lanata* (Willd.) Bullock	Herb	Zygophyllaceae
88	*Senna italica* Mill.	Herb	Caesalpiniaceae
89	*Sesuvium portulacastrum* L.	Herb	Aizoaceae
90	*Sida cordifolia* L.	Herb	Malvaceae
91	*Solanum albicaule* Kotschy ex Dunal	Herb	Solanaceae
92	*Solanum xanthocarpum* Schrad. & Wendl.	Herb	Solanaceae
93	*Trianthema portulacastrum* L	Herb	Aizoaceae
94	*Tribulus pentandrus* Forsk var. *pentandrus*	Herb	Zygophyllaceae
95	*Tribulus terrestris* L.	Herb	Zygophyllaceae
96	*Trichodesma indicum* (L.) R.Br.	Herb	Boraginaceae
97	*Verbesina encelioides* (Cav.) Benth. & Hook. f.	Herb	Asteraceae
98	*Vernonia cinerea* (L.) Less.	Herb	Asteraceae
99	*Xanthium strumarium* L.	Herb	Asteraceae
100	*Cadaba fruticosa* (L.) Druce	Lianas	Capparaceae
101	*Cocculus pendulus* (J.R.Forst. & G.Forst.) Diels	Lianas	Menispermaceae
102	*Pentatropis spiralis* (Forssk.) Decne.	Lianas	Asclepiadaceae
103	*Cyperus alopecuroides* Rottl.	Sedge	Cyperaceae
104	*Cyperus arenarius* Retz.	Sedge	Cyperaceae
105	*Cyperus pygmaeus* Rottb.	Sedge	Cyperaceae
106	*Cyperus rotundus* L.	Sedge	Cyperaceae
107	*Acacia jacquemontii* Benth.	Shrub	Mimosaceae
108	*Aerva persica* (Burm. f.) Merr.	Shrub	Amaranthaceae
109	*Aerva pseudotomentosa* Blatter & Hallberg.	Shrub	Amaranthaceae
110	*Calotropis procera* (Aiton) W.T. Aiton.	Shrub	Asclepiadaceae
111	*Clerodendron phlomoides* L.	Shrub	Verbanaceae
112	*Crotalaria burhia* Buch.-Ham.	Shrub	Papilionaceae
113	*Euphorbia caducifolia* Haines	Shrub	Euphorbiaceae
114	*Grewia tenax* (Forssk.) Fiori	Shrub	Tiliaceae
115	*Leptadenia pyrotechnica* (Forsk.) Decne	Shrub	Asclepiadaceae
116	*Lycium barbarum* L.	Shrub	Solanaceae
117	*Mimosa hamata* Willd.	Shrub	Mimosaceae
118	*Withania somnifera* L. Dunal	Shrub	Solanaceae
119	*Ziziphus nummularia* (Burm. f.) Wight et Arn.	Shrub	Rhamnaceae
120	*Citrullus colocynthis* (L.) Schrad.	Trailer	Cucurbitaceae
121	*Convolvulus microphyllus* Sieb. ex Spreng.	Trailer	Convolvulaceae
122	*Acacia nilotica* (L.) Willd. ex Del	Tree	Mimosaceae
123	*Acacia senegal* (L.) Willd.	Tree	Mimosaceae
124	*Acacia tortilis* (Forssk.) Hayne	Tree	Mimosaceae
125	*Azadirachta indica* A. Juss	Tree	Meliaceae
126	*Balanites aegyptiaca* (L.) Del.	Tree	Balanitaceae
127	*Capparis decidua* (Forssk.) Edgew	Tree	Capparaceae
128	*Cordia gharaf* (Forssk.) Ehren. ex Asch.	Tree	Ehretiaceae
129	*Maytenus emarginata* (Willd.) Ding Hou.	Tree	Celastraceace
130	*Prosopis cineraria* (L.) Druce	Tree	Mimosaceae
131	*Prosopis juliflora* (Sw.) DC.	Tree	Mimosaceae
132	*Salvadora persica* L.	Tree	Salvadoraceae
133	*Tecomella undulata* D.Don	Tree	Bignoniaceae
134	*Ziziphus mauritiana* Lam.	Tree	Rhamnaceae
135	*Ziziphus rotundifolia* Lam.	Tree	Rhamnaceae
136	*Ipomea pes-tigridis* L.	Twinner	Convolvulaceae
137	*Ipomoea nil* (L.) Roth	Twinner	Convolvulaceae
138	*Tephrosia leptostachya* DC.	Undershrub	Papilionaceae
139	*Tephrosia purpurea* (L.) Pers.	Undershrub	Papilionaceae
140	*Abutilon indicum* (L.) Sweet	Undershrub	Malvaceae