

Magnitude of temporal fluctuations of composite environment and their impacts on *Cassia auriculata* (Linn.) performance

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Abstract: Aim of the present study was to access the temporal impacts of energy, community and edaphic variables on performance of a woody perennial *Cassia auriculata*, and thus, to evaluate role of this species during various resource pulse events in hot arid region. Different environmental (top-down and bottom-up) and species variables were temporally quantified at six arid younger alluvial sites of the Indian Thar desert. Functional traits like morphological (canopy volume, height and cover), physiological (maintenance respiration, construction cost, total respiration, GPP, NPP) and population (Relative Importance Value) of this species were affected by the energy (net radiation, incoming solar radiation, AET and transpiration), community (diversity, richness and evenness) and edaphic factors (soil organic carbon, nitrogen, phosphorus, moisture, pH, and electrical conductivity). 31 significant dependent-exploratory relationships were established and out of which 19 and 12 were linear and non-linear, respectively. Incoming net shortwave radiation and incoming solar radiation above $14.5 \text{ MJ m}^{-2} \text{ day}^{-1}$, $17.89 \text{ MJ m}^{-2} \text{ day}^{-1}$ were identified as a priority for the maintenance respiration and for total respiration, respectively. Threshold limits of AET (18.55–38.77) and transpiration (18.15–25.96 mm) for canopy volume were also identified. With response to environmental fluctuations this species adopted different survival mechanisms without affecting community associates. During non-resource conditions this species can be used as vertical sheet against wind and soil erosion while, during resource availability it serves as nurse plant for other species and supports species richness. Further, identification of such traits and their associated influencing variables are essential for mechanistic understanding about the species-specific role in ecosystem processes as well as for enhancing the use values of a species.

Key words: *Cassia auriculata*, diversity and species traits, soil factors, solar energy, species richness.

Introduction

Climate appears to determine the region specific adaptability of a species, whereas the weather regulates day-to-day growth and development of plants and plants influence their own microclimate (Mathur 2014). The comportment of bottom-up (energy variables and community dynamics) and top-down (edaphic micro-climate) factors control the growth, development, and survival of producers and consumer of various trophic levels. At community level workers (Grace

et al. 2007; Hardwick *et al.* 2015; Kahmen *et al.* 2005; Poorter *et al.* 2012; Song *et al.* 2016; Wang *et al.* 2015) quantified biotic and abiotic impacts on plant traits and majority of such studies were conducted at tropical grasslands, tallgrass prairie, tropical rain forest and European grasslands. However, such studies are rare at hot arid regions (Mathur 2014).

In arid region, temporal fluctuations are very important for physiological and population dynamics of a species (Mathur & Sundramoorthy 2016). In such region, “two-phase resource hypothesis”

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(Goldberg & Novoplansky 1997) explained the distinction between the period when resources are adequate ('pulse') and when resources are too low for plant use (inter-pulse and non-pulse) and these resource pulses are deciphered important factor for desert plant physiological and community dynamics (Mathur 2013). James *et al.* (2006) had examined the behaviour of resource pulses and temporal variation in assets demand by the invasive annual grass, *Schismus arabicus* at the Mojave Desert. They found that *Schismus* density and biomass were highly dependent on the seasonal timing of the resource pulses and the specific identity of the neighbour's shrub. Many ecophysiological studies have also demonstrated that functional groups and life stages of desert plant species differs in their capacity to use resource pulses (Mathur & Sundaramoorthy 2017; Naz *et al.* 2014; Shen *et al.* 2015; Zhang *et al.* 2017). Thus, knowledge of plant performance with fluctuating environment would guide us to develop a resilient and sustainable ecosystem.

Present study hypothesized that in arid regions plant community associates are scattered and at the species level, responsiveness of species functional traits and population dynamics may vary with biotic and abiotic factors. Thus, observations on species characteristics oscillation by taking into account of bottom-up and top-down factors would help us to understand appropriate use of a species in arid ecosystem. To work out this, temporal compartments of functional traits (physiological and morphological) and population attributes of *Cassia auriculata* were quantitatively evaluated with relation to energy, community and edaphic factors at six arid younger plains of the Indian region.

Cassia auriculata (Caesalpinaceae) is a hardy perennial shrub attaining up to a height of 2 m and commonly present at wastelands and roadsides. This species is reported to have provisional (medicinal uses) and regulatory (nitrogen fixation) ecosystem services (Joy *et al.* 2012). Its pollination strategy was studied by Shivanna (2015), while Dixit and Rao (2000) found its negative association with *Commiphora wightii*. Sinha *et al.* (2000) had identified the sand dune stabilization properties of this species along with other shrubs like *Calligonum polygonoides*, *Cassia auriculata*, *Ricinus communis*, *Zizyphus nummularia* and grasses like *Lasiurus sindicus*, *Panicum turgidum*, *Erianthus munia* etc. However, no efforts have been carried out towards its ecophysiological responses with respect to composite environmental conditions.

Materials and methods

Area characterization

Study was carried out at six different arid sites (26°11'33"N, 72°56'5.9"E to 27°21'54.5"N, 73°4'7.8"E) of the Indian hot desert. These sites were located at younger alluvial plain habitat with a higher proportion of sand (54.6%) and gravel (30.2%). Data were collected during three different events, viz. pulse event (pulse season; July to October), inter-pulse event (Inter-pulse; November, December, January and February) and non-pulse event (non-pulse, March to June). Different meteorological parameters were collected from the meteorological section of Central Arid Zone Research Institute (CAZRI), Jodhpur. During the study period, mean annual precipitation ranged from 0.004 to 260 mm, average inter-pulse (January) temperature ranged from 10.7 °C to 23.0 °C, and mean non-pulse (June) temperature ranged from 28.7 °C to 42.2 °C. Relative humidity ranged from 31% to 91% in the morning and from 8% to 68% in the evening.

Plant sampling

During each event and from each site, fifteen plants were randomly selected. Canopy volume was quantified according to shape criteria of species provided by Ludwig and Reynolds (1975) with radius and height in meter. Biomass was quantified following the non-harvest method by using equation pertains with crown radius and shoots height (Dai *et al.* 2009). Total biomass was quantified by summing-up above ground biomass and below ground biomass (BGB was quantified using 0.3 multiplication factors with the AGB as per Chave *et al.* 2005). Species (total biomass, height, cover, density, frequency, abundance, Relative Importance Value: RIV) and community (richness and diversity parameters) traits were quantified by following Ludwig & Reynolds (1988). Leaf-area index was calculated by using LICOR-3000 area meter. GPP was calculated from the total NPP plus the total respiration. Carbon content was determined by Walkley and Black's method (Sahrawat 1982), and the total nitrogen was estimated by micro-Kjeldahl method (Jackson 1973). Ash content was determined after heating the dry matter to 550 °C for 5 hours (Sanjerehei 2013). Different edaphic variables like soil organic carbon, nitrogen, phosphorus, moisture, pH and electrical conductivity were quantified according to Jackson (1973).

Total respiration

Total respiration was calculated by using maintenance respiration (R_m) and construction cost (CC). For estimate AGB, the R_m was quantified by applying following formula (Mathur & Sundaramoorthy 2017).

$$R_m = \text{Total biomass} \times D \times T_N \times \exp(0.07 \times T_a)$$

Where T_N is the total nitrogen content, T_a is the average growing season temperature ($^{\circ}\text{C}$) and D is the duration of growing season (number of days).

Construction cost (Coste *et al.* 2011) was calculated using following formula:

$$CC = \left(\frac{5.007 \times C_m}{1 - \text{Min}} - 1.04 \right) \times (1 - \text{Min}) + 5.325 \times N_{\text{org}}$$

Where CC is the construction cost (g glucose g^{-1} dry weight), C_m is the total carbon content; Min is the mineral (ash content) and N_{org} is the organic nitrogen concentration of the total dry matter (g g^{-1}). The original method was provided by Poorter (1994). Coste *et al.* (2011) utilised the above-mentioned modified methods in which nitrate reduction in non-photosynthetic tissues was also taken into account ($5.325 \times N_{\text{org}}$). This computation assumes that all nitrogen is absorbed as nitrate.

Solar-energy capture

Amount of utilised solar energy was determined as the sum of the energy fixed as GPP and the energy consumed in transpiration. The energy fixed as GPP was determined on the basis of glucose equivalent of the carbon fixed in plants as GPP ($\text{C}_6/\text{C}_6\text{H}_{12}\text{O}_6 = 72/180$) and the energy required to produce glucose (3740 cal g^{-1} glucose, Sanjerehei 2013).

Energy used in transpiration

The energy necessary to evaporate water at the mean temperature during the growing season was calculated by using Harrison (1963) equations, as follows:

$$\lambda_v = 597.3 - 0.564 T$$

where λ_v is the latent heat of vaporisation (cal g^{-1}) and T is the mean temperature in the growing season ($^{\circ}\text{C}$).

Transpiration (T_R) was estimated by partitioning evapotranspiration into evaporation and transpiration (Campbell 1985), as follows:

$$T_R = \text{AET} [1 - \exp(-0.82F)]$$

where AET is the actual evapotranspiration

and F is the leaf area index. The actual evapotranspiration (mm) during the growing season was calculated by following equation:

$$\text{AET} = P - \exp\left(\frac{\text{PET}}{P}\right)$$

where P is the mean annual precipitation (mm) and PET is the potential evapotranspiration (mm) during the growing season, calculated from Thornthwaite's (1948) method, as follows:

$$\text{PET} = 16 \left(\frac{16}{12}\right) \left(\frac{N}{30}\right) \left[\frac{10 T}{I}\right]^a$$

where T is the average temperature ($^{\circ}\text{C}$) during the particular pulse event, L is the average day length (h) during the pulse events, N is the number of days and I is the heat index. The heat index was calculated as:

$$I = \sum_{i=1}^n \left[\frac{T_i T}{5} \right]^{1.514}$$

where T_i is the average temperature during the pulse event; a was calculated as:

$$a = 0.49239 + 0.0179I - 0.000077I^2 + 0.000000675I^3$$

Determination of solar radiation

To evaluate the percentage of the energy utilised by the plant in photosynthesis and transpiration, incoming solar radiation and net solar radiation were determined. Net radiation (R_n , $\text{MJ m}^{-2} \text{day}^{-1}$) was estimated by an equation provided by Allen *et al.* (1998) as follows:

$$R_n = R_{\text{ns}} - R_{\text{nl}}$$

where R_{ns} is the incoming net shortwave radiation and R_{nl} is the outgoing net longwave radiation.

$$R_{\text{nl}} = (1 - \alpha) \times R_s$$

where α is the albedo or canopy reflection coefficient (0.23) and R_s is the incoming solar radiation ($\text{MJ m}^{-2} \text{day}^{-1}$) which was determined as follows:

$$R_s = \left[0.25 + 0.5 \left(\frac{n}{N}\right) \right] \times R_a$$

where n is the actual duration of sunshine (h), N is the maximum possible duration of sunshine, r daylight hours (h) obtained from:

$$N = \frac{24 \omega_s}{\pi}$$

where ω_s is the sunset hour angle and it is calculated as:

$$\omega_s = \arccos[-\tan(\omega)\tan(\delta)]$$

where ω is the latitude (red) and δ is the solar decimation (red), calculated as:

$$\delta = 0.409 \left(\frac{2\pi}{365} J - 1.39 \right)$$

where J is the number of days in the particular pulse event and R_a is the extraterrestrial radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$).

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \times \sin(\varphi) \times \sin(\delta) + \cos(\varphi) \times \cos(\delta) \times \sin(\omega_s)]$$

where $G = sc$ is the solar constant ($0.082 \text{ MJ m}^{-2} \text{ min}^{-1}$), and d_r is the inverse relative distance earth–sun, as follows:

$$d_a = 1 + 0.033 \cos \left(\frac{2\pi}{365} J \right)$$

The outgoing net longwave radiation was determined as:

$$R_{nl} = \sigma \left[\frac{T_{max,k}^4 + T_{min,k}^4}{2} \right] (0.34 - 0.14\sqrt{e_a} \left(1.35 \frac{R_s}{R_{so}} - 0.35 \right))$$

where σ is the Stefan–Boltzmann constant ($4.903 \times 10^{-9} \text{ MJ K}^{-4} \text{ m}^{-2} \text{ day}^{-1}$), $T_{max,k}$ and $T_{min,k}$ are daily maximum and minimum absolute temperatures (K), respectively, e_a is the actual vapour pressure (kPa).

$$e_a = 0.6108 \exp \times \left[\frac{17.27 T}{T + 237.3} \right]$$

$\exp = 2.7183$ (base of natural logarithm) raised to the power.

$$R_{so} = (0.75 + 2 \times 10^{-5} Z) \times R_a$$

Statistical analysis

Strip-plot ANOVA analysis was performed to evaluate impact of seasonal events and sites on species height, plant cover, canopy volume, biomass, organic carbon, nitrogen and ash contents. Significance of variability in community and soil variables during various events were evaluated through student t-test. Suitability of factorial analysis was checked with Bartlett test of sphericity and Kaiser-Meyer-Olkin (KMO). Principal Component Analysis (PCA) is as a data reduction technique and it was utilized to identify the extent and directions of multivariate controls of different environmental variables on species traits. Appropriate regression equations were selected on the basis of probability level significance with R^2 value (with $n-2$ degrees of freedom (i.e. $6-2 = 4$ df $5\% = 0.811$ and $1\% = 0.917$). It was carried out with the help of Curve Expert (2001) software.

Results

Environmental and species variables

During the study period, maximum heat index (attribute of average monthly temperature) was recorded during non-pulse event, followed by pulse and inter-pulse events. Potential evapotranspiration (mm), which is an indication of energy availability, was more or less similar during inter-pulse and non-pulse events, whereas the actual evapotranspiration (energy–water balance) which is based on mean precipitation (mm) was higher during pulse event followed by inter-pulse and non-pulse events (Table 1). Both precipitation and leaf-area index contribute to transpiration and this was recorded higher during pulse and least during non-pulse event.

Latent heat of vaporization was higher during an inter-pulse ($585.35 \text{ cal g}^{-1}$) and was lowest (488 cal g^{-1}) during non-pulse. Extraterrestrial radiation ($21.45 \text{ MJ m}^{-2} \text{ day}^{-1}$), outgoing net long wave ($5.55 \text{ MJ m}^{-2} \text{ day}^{-1}$), incoming net shortwave ($15.72 \text{ MJ m}^{-2} \text{ day}^{-1}$), net radiation ($10.5 \text{ MJ m}^{-2} \text{ day}^{-1}$), incoming solar radiation ($20.4 \text{ MJ m}^{-2} \text{ day}^{-1}$) and actual vapour pressure (2.62 kPa) were recorded higher during non-pulse. Maintenance respiration provides energy for the plant processes such as maintenance of ion gradients across membranes, protein repair and replacement- and translocation-related processes that do not result in a net gain in biomass but keep existing phyto-mass in a healthy state and it was calculated through tissue nitrogen and mean annual temperature. Total respiration, the construction cost ($\text{g glucose g}^{-1} \text{ DW}$) and maintenance respiration were recorded higher during non-pulse event and was minimum during pulse event. Trends of other variables are also presented in Table 1. Species, community and soil variables quantified during the study period are depicted in Table 2. Height, canopy volume, cover, total biomass and relative importance value (RIV) of *C. auriculata* showed a progressive increase from pulse to inter-pulse and non-pulse periods. Plant organic carbon, nitrogen, and ash content were recorded higher during non-pulse period followed by pulse and inter-pulse.

Statistical interpretation

ANOVA analysis revealed the significant contributions of both site and event factors as well

Table 1. Energy variables and species efficiency during three seasonal events.

	Parameters	Pulse	Inter-pulse	Non-pulse
Energy Variables	Heat Index	3.85	2.23	3.91
	Potential evapotranspiration (PET, mm)	1.70	1.96	1.93
	Actual evapotranspiration (AET, mm)	52.84	38.32	27.50
	Transpiration	36.07	25.96	18.55
	Latent Heat (λ_v Cal g^{-1})	580.30	585.35	488.00
	R_n (Net radiation, $MJ m^{-2} day^{-1}$)	9.66	8.64	10.50
	R_{ns} (incoming net shortwave radiation, $MJ m^{-2} day^{-1}$)	13.78	14.13	15.72
	R_{nl} (Outgoing net long-wave radiation, $MJ m^{-2} day^{-1}$)	4.11	5.21	5.55
	R_a (Extraterrestrial radiation, $MJ m^{-2} day^{-1}$)	21.39	21.24	21.45
	e_a (Actual vapour pressure, kPa)	2.59	1.87	2.62
	R_s (Incoming Solar radiation, $MJ m^{-2} day^{-1}$)	17.89	18.35	20.41
	R_m (Maintenance Respiration (Total R - Construction R_c))	23.80	24.95	49.11
	R_c (Construction Cost (CC, g glucose g^{-1} DW))	6.07	8.02	9.86
	Total respiration	29.87	32.97	58.97
Species efficiency	NPP (Net Primary Production)	22.65	61.79	74.91
	GPP (Gross Primary Production)	52.52	94.76	133.88
	CUE (Carbon Use Efficiency i.e. NPP:GPP)	0.43	0.65	0.55
	R:GPP	0.44	0.34	0.56
	Conversion efficiency of the extraterrestrial radiation to NPP	94.43	34.37	26.55
	Conversion efficiency of the annual incoming solar energy to GPP	34.05	19.36	15.24

Table 2. Species (*Cassia auriculata*), community and soil dynamics during three seasonal events.

	Parameters	Pulse	Inter-pulse	Non-pulse
Species variables	Height (m)	0.93±0.60	1.08±0.01	1.28±0.14
	Canopy volume	0.24±0.10	0.71±0.41	0.78±0.23
	Cover	0.74±0.09	1.28±0.34	1.55±0.43
	Total biomass	29.45±9.11	80.2±19.69	97.38±24.48
	RIV	11.01±2.80	15.11±3.70	23.21±3.79
	Organic carbon	42.21±8.33	16.76±5.31	61.97±5.10
	Nitrogen	10.68±2.62	8.63±1.54	24.12±1.95
	Plant ash	0.86±0.07	0.77±0.13	1.109±0.08
Community Dynamics	Richness	12	8	5
	Shannon and Weaver Index (H')	2.1	1.52	1.18
	Simpson Index	0.16	0.26	0.38
	Evenness	0.93	0.7	0.49
Soil Factors	Soil organic carbon	67.25±16.59	161.95±5.73	181.84±17.18
	Soil phosphorus	38.98±8.87	29.66±5.73	12.42±14.88
	Soil nitrogen	45.89±9.10	63.80±8.72	74.48±14.88
	Soil pH	8.30±0.84	7.30±0.74	7.65±0.61
	Soil electrical conductivity	0.26±0.14	0.21±0.04	0.15±0.07
	Soil moisture	8.75±2.70	1.42±0.66	0.93±0.40

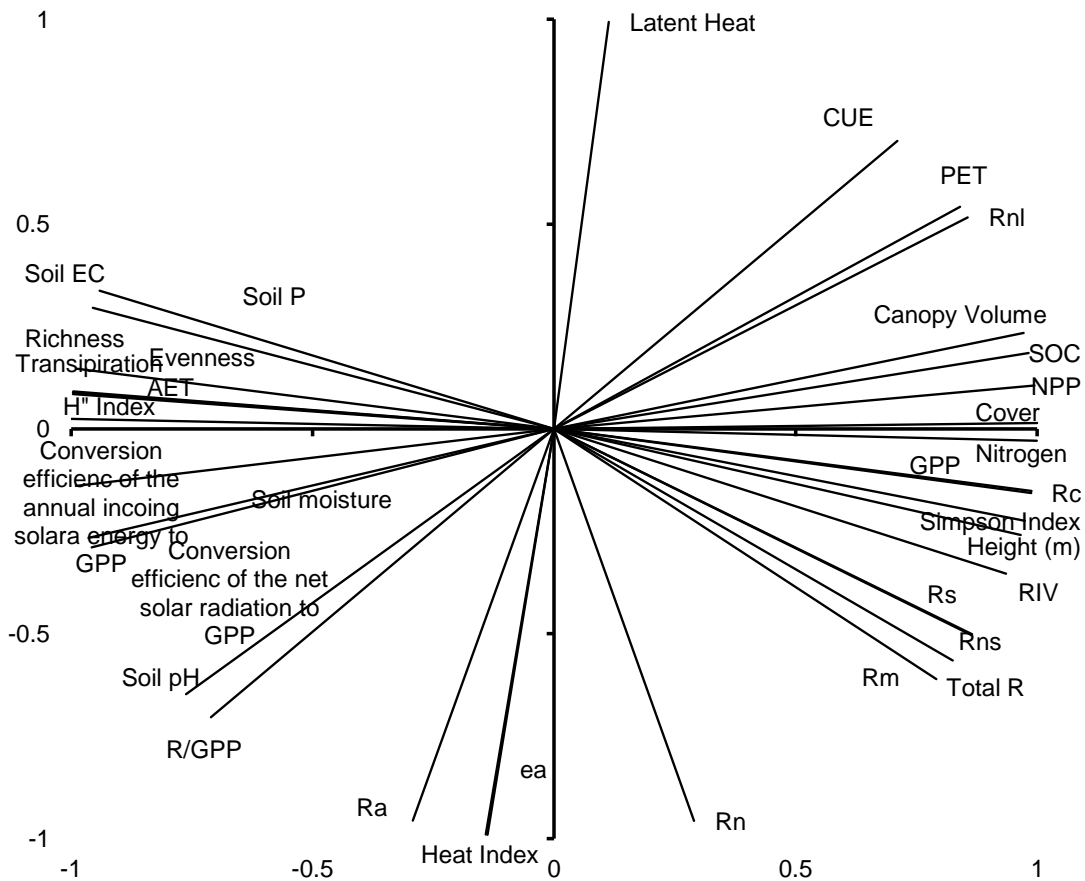


Fig. 1. Biplot of Principal Component Analysis.

as their interactions for most of the species parameters, except for total biomass (Table S1). Student *t*-test suggested significant inter-seasonal variations for community and soil parameters; however, it was non-significant for soil electrical conductivity (Table S2).

To testify the multivariate controls on plant performance, two tests viz., Kaiser-Meyer-Olkin (KMO) and Barlett test of sphericity were used. KMO index represents appropriateness of factor analysis and values between 0.5 and 1.0 indicates the appropriateness of the factor analysis. In the present study, it was recorded 0.784, which expedience its use (Table S3). For Barlett's test of sphericity two alternative null hypotheses exists i.e. H_0 : no correlation between the variables, and H_a : significant correlation between variables. According to its interpolation, as the computed *P*-value is lower than the significance level ($P < 0.05$), that suggested significant relationships between variables (Table S3). Thus, pointing to the multivariate control on

species performance. Thus, a direct and indirect gradient (related to energy variables, soil factors, and community variables) plays crucial role for productivity and population dynamics.

In present study, cumulative percentage of PCA analysis indicates that first two axes together accounted 100% variability in the data set (Table S4) with their individual contribution being 74% and 26%, respectively (Fig. 1), and this proved the use of this tool (as cumulative percentage of variance approached 80%, Wei-Giang *et al.* 2008). It has been found that among 34 different variables 29 variables were significantly associated with F1 component, while remaining 5 related with F2 component. PCA biplot explained that there is no arch effect and components are well dispersed at all axes of the biplot. Actually this biplot is generated and revealed the linear relationships between exploratory and dependent variables, which are the major limitation with PCA, hence, regression analysis was carried out to know the exact pathway

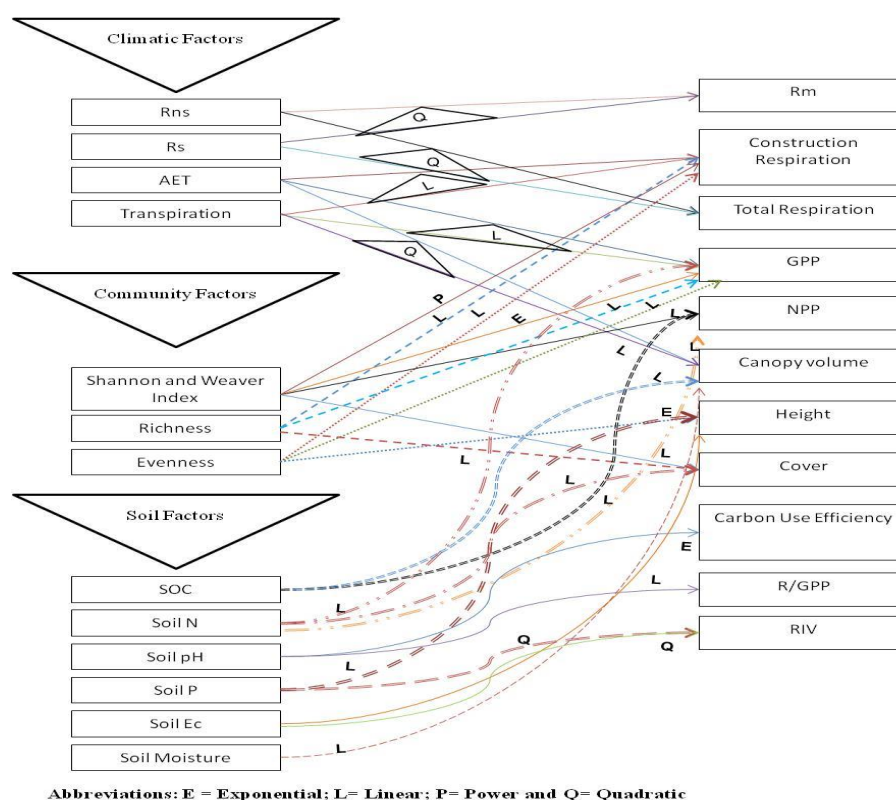


Fig. 2. Relationships of various exploratory and dependent variables.

for such relationships. For each component, variable with loading >0.70 were identified as significant variable and used for path analysis (Mathur & Sundaramoorthy 2017).

Regression analysis

Energy variables

Present study suggested that energy, community and soil factors influence the various morphological, physiological and population attributes of *C. auriculata* (Table S5 and Fig. 2). Incoming net shortwave radiation (Rns) and incoming solar radiation affected the maintenance respiration ($R^2 = 1.00^{**}$) and total respiration ($R^2 = 1.00^{**}$) in non-linear (quadratic) fashion. NPP and GPP have been shown to have a strong pattern along environmental gradients. Variables such as temperature and precipitation affect NPP directly through their effect on the physiological processes of photosynthesis, respiration and plant growth. In this study, actual evapotranspiration (AET) and transpiration inversely and linearly affected the construction respiration and gross primary productivity significantly ($R^2 = 0.99^{**}$) and canopy volume in non-linear manner (quadratic $R^2 = 1.00^{**}$).

Community variables

It was found that all the community variables were inversely proportional to plant performance. Among the community parameters, species richness showed significant ($R^2 = 0.99^{**}$) relationships with construction respiration, GPP and plant cover. Evenness also controls construction respiration and GPP ($R^2 = 0.99^{**}$) in a linear fashion while it affected the height in an exponential manner ($R^2 = 0.99^{**}$). Diversity parameters like Shannon and Weaver index (H') influenced construction respiration and GPP ($R^2 = 0.99^{**}$) in power and exponential fashions and NPP and plant cover ($R^2 = 0.99^*$) in linear manner.

Soil variables

Soil nitrogen linearly and positively supports GPP and plant cover ($R^2 = 0.99^{**}$) and SOC also showed similar relationships with NPP ($R^2 = 0.99^{**}$). SOC and soil moisture also exhibited linear relationships with canopy volume ($R^2 = 0.99^{**}$). The present study revealed that the plant height inversely and linearly controlled by soil phosphorus ($R^2 = 0.99^{**}$) and by electrical conductivity ($R^2 = 0.99^{**}$), while both these two exploratory factors

controls the dominance (RIV) of this species in non-linear fashion (quadratic, $R^2 = 1.00^{**}$). Soil pH also affects the carbon-use-efficiency of this species ($R^2 = 0.99^{**}$) in an exponential manner and this similar factor also crucial for ration of respiration to GPP ($R^2 = 0.99^{**}$) in a linear fashion.

Discussion

Plant productivity is a complex phenomenon regulated by environmental, edaphic, and community factors and their utilization efficiency ascertain by species traits. Gross primary production (GPP) represents the capacity of the plants in an ecosystem to capture energy and carbon, NPP (reduction of GPP after autotrophic respiration) is the net carbon stored as new plant material in an ecosystem that supplies resources in the form of various ecosystem services. Present study revealed that 18.55–38.7 mm AET supports the GPP and beyond this limit it reduces drastically. Thus, the use of GPP of such species at the places where desired AET is available will facilitate us for more carbon sequestration. The conversion efficiency of the annual incoming solar energy to the GPP and conversion efficiency of the extraterrestrial radiation to the NPP shows reverse trends as recorded being maximum during pulse events followed by inter-pulse and least during non-pulse event. The amount of NPP of *C. auriculata* during inter-pulse and non-pulse events found to be higher than that of *Artemisia* ($51.1 \text{ C m}^{-2} \text{ yr}^{-1}$) quantified by Sanjerehei (2013) from central arid part of the Iran. The NPP can be correlated with rainfall event, leaf-area index and other soil resources. Country based analysis of NPP by Ito and Inatomi (2012) concluded the relationships between NPP and water availability. Further, NPP also depends upon the degree of habitat utilization by consumer organism (Mathur 2014) and as this species is non-palatable, thus, non-grazing traits also contribute in its NPP.

Incoming net shortwave radiation and incoming solar radiation above $14.5 \text{ MJ m}^{-2} \text{ day}^{-1}$ and $17.89 \text{ MJ m}^{-2} \text{ day}^{-1}$, respectively, are crucial for maintenance respiration and for total respiration, respectively. Canopy volume which represents the extension of plant part i.e. indirect net carbon stored in these new parts. In the present study, it was noticed that AET and transpiration were controlled canopy volume in non-linear manner, and 18.55–38.77 mm and 18.15–25.96 mm were recorded as threshold for this plant parameter, respectively. This indicated that AET condition

(18.55–38.77 mm) is very crucial for this species and for the communities where it acted as an indicator species and such information are very crucial for restoration planning of arid lands.

Carbon-Use-Efficiency (CUE) is an important control mechanism for carbon storage in ecosystems (Ise *et al.*, 2010; Manzoni *et al.*, 2012). It is the proportion of carbon acquired from the environment that is used for growth. For example, a higher temperature reduces CUE while higher nitrogen availabilities increased it (Vicca *et al.*, 2012). Several researchers have found that the carbon-use efficiency (CUE, NPP: GPP ratio) is relatively stable and independent of ecosystem type (Gifford 1994), and constant across a range of CO_2 levels and temperatures for herbaceous and woody plants (Cheng *et al.* 2000; Tjoelker *et al.* 1999). Waring *et al.* (1998) suggested that a universal value of 0.47 is appropriate for most ecosystems. However, this assumption has been tested only in limited ways, thus, creating uncertainties about its global application (Xiao *et al.*, 2003). DeLucia *et al.* (2007) conducted a metadata analysis and found that the NPP:GPP ratio ranged from 0.23 to 0.83 for different forest types. Zhang *et al.* (2009) reported spatial variation in CUE associated with ecosystem type, geographical location, and climate. These authors further reported that densely vegetated ecosystems had lower CUE than did sparsely vegetated ones; similarly, forest ecosystems had a lower CUE than did shrub and herbaceous ecosystems. The discussed phenomenon has already been tested through habitat/species that are apparently useful for human being (forest land, crop lands), but there lies an apparent gap in our understanding for the species of arid wasteland/grazing lands (Mathur 2014).

In the present study, CUE was recorded higher during non-pulse event (Table 1). CUE results indicated that GPP is approximately 1.5 times higher to NPP across different events. Temporal variations in CUE can be explained with the previous studies (Cheng *et al.* 2000; Dewar *et al.* 1998; Gifford 1994; Landsberg & Gower 1997; Landsberg & Waring 1997; Tjoelker *et al.* 1999) suggested that nitrogen and temperature are the most crucial for such type of result. In the present study, higher CUE during a non-pulse event may contribute through high soil nitrogen content (Vicca *et al.* 2012).

Incoming net shortwave and incoming solar radiation had positive impact on construction cost, total respiration, NPP, GPP and CUE while, AET and transpiration showed reverse trend to this.

Such mechanistic controls can be explained with the fact that when respiratory products are consumed rapidly (i.e. growth accumulation), however, negative feedbacks on respiration are also regenerated, with the result that respiration rate increases. This further associated with biochemical uncouples, which break the links between respiration rate and the use or turnover of respiratory products and resultant in elevated respiration rate (Amthor & Baldocchi 2001).

From the Indian arid and semiarid areas, Shankar *et al.* (1977) and Pandya & Sidha (1989) summarized that photosynthetically active radiation, water potential and silica content affected the NPP of *Cenchrus ciliaris*, *Sporobolus helvulus*, *Desmostachy bipinnata*, *Eragrostis tennella* and *Cenchrus biflorus*. In the present study, the total NPP and GPP were found to be lower than those of forest ecosystem (e.g. 307 g C m⁻² yr⁻¹ for *Picea mariana* in boreal forest; 960 g C m⁻² yr⁻¹ for *Pinus radiata* in temperate coniferous forests, 817 g C m⁻² yr⁻¹ for *Betula ermanii*, *B. platyphylla* and *Quercus Mongolia* in temperate deciduous forest and temperate grasslands, 1207 and 1140 g C m⁻² yr⁻¹ in a *Miscanthus sinensis* grassland in Japan (Sanjerehei 2013). Relationships of evapotranspiration with construction respirations and gross primary productivity have also been advocated by Tian *et al.* (2010) where they have linked such pattern with buffering capacity and trait values of desert species. Larjavaara and Muller-Landau (2011) provided the framework for dual effects of temperature on GPP and total maintenance cost and according to them the ratio of GPP to maintenance cost per unit biomass (MCB) peaks at 16.5 °C, indicating that this is the air temperature leading to the highest possible AGB when temperatures are constant.

In this study construction respiration, GPP, and plant cover are linearly and negatively controlled by species richness, evenness and Shannon Weaver diversity. Species richness, diversity and evenness in the range of 4.5–7.3, 1.2–1.5 and 0.5–0.8, respectively, are appropriate for these dependent parameters. In view of negative relationships of diversity parameters with its plant cover, it can be hypothesized that during high diversity and evenness this species changes their organ morphology and may invest more in their underground part. Thus, ultimately not affects the community composition. However, we did not found such relationships with RIV of this species. This hypothesis also supported with one of the associated parameters i.e. height which linearly controlled

through evenness. Thus, this species works with two mechanisms: (1) during resource conditions, it invests more in its underground portion to avoid any competitions with their associates, that ultimately save its energy, and (2) during stress conditions, it utilized its deep root system for resource acquisitions and emerged as successful species with high canopy volume. Such results are also supported by study of Zhang *et al.* (2017) where they reported organ specific strategy for drought adapted by *Caragana korshinskii*.

Diversity-productivity relationships for natural ecosystems by using univariate (regression and ANOVA) and multivariate models have been reviewed by Grace *et al.* (2007) and found a conspicuous non-linear relationships between them, while Cardinale *et al.* (2009) discussed the impact of diversity on productivity (NPP and GPP) through Multivariate-Productivity-Density. Poorter *et al.* (2012) have reviewed the biomass allocation patterns to leaves, stem and root and their metanalysis suggested that plant generally are less able to adjust allocation than to alter organ morphology. Study of Pedro *et al.* (2015) showed that NPP and total carbon stock were reduced by increasing species richness, particularly in systems with low richness levels. In the present study (at species level), exponential and linear decrease of GPP were recorded with diversity (H' index) and richness, respectively. Such results indicated high competitive trait of this species, specifically when other associates failed to survive. Higher soil organic carbon, nitrogen and canopy volume and NPP of this species were recorded during non-pulse event indicating synergism between resources availabilities and plant productivity. Further higher canopy volume during low soil moisture condition suggested that this species having deeper root system that enable it to flourish more during stress condition and similar results were also reported for *Prosopis juliflora* shrub from the Kenya arid region by Kahi *et al.* (2009). Quadratic decrease of RIV of this species with increase in soil P can also be explained with the studies of Henkin *et al.* (2006) and Osman *et al.* (1999) which showed that the phosphorus addition significantly supports richness and biomass of annuals compare to perennials. Further, compared to Blaser *et al.* (2014) study on *Dichrostachys cinerea* shrub, *Cassia auriculata* create a positive feedback loop during the P-limiting condition.

Based on the temporal species performance with respect to different exploratory variables, *C. auriculata* provides higher ground cover to control wind and soil erosion during no resource

availability. While during resource availability it can serve as nurse plant/or fertility of island to provide favourable conditions for recruitment of other new species, and thus, increasing species richness.

Conclusions

The present study provides a broader insight about how the energy, soil, and community variables affected the *Cassia auriculata*. Identification of such functional traits and their associated influencing variables are essential for mechanistic understanding of the species-specific role in ecosystem functions. Thus, present results can be utilized in planning to develop more resilient community.

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Supporting Information

Additional Supporting information may be found in the online version of this article.

Table S1. ANOVA analysis for different plant traits.

Table S2. Student *t*-test for community and soil parameters.

Table S3. Bartlett's sphericity and Kaiser-Meyer-Olkin sampling adequacy tests

Table S4. Eigen value analysis and other attributes obtained from PCA

Table S5. Regression equations with independent and dependent variables