ISSN 2250-3153

Differential Biomass Allocation to Above-Ground Plant Components by Two Invasive *Sida* Congeners in a Dry Tropical Peri-Urban Vegetation in India

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Abstract- Differing biomass allocation strategy could be a necessary plant-trait associated with invasive weeds in an alien environment. The present study focused on exploring differential biomass allocation pattern as an invasive plant-trait in the two pantropical invasive malvaceous weeds *Sida acuta* Burm f. and *Sida cordifolia* L. in an anthropic peri-urban vegetation in Indian dry tropics. Eighty plant individuals from each of these two congeners across their varying developmental stages were clipped off from their dominantly growing study site at the polluted bank of Kali river in Bulandshahr (28º04' & 28º43' N lat. and 77º08' & 78º28' E long.) in the national capital region of India. The plant individuals were separated into different above-ground plant components (leaf, stem-axis, branch and reproductive parts that included flowers/capsules/seeds). They were oven-dried, weighed and the mass fractions of each component estimated as its dry weight relative to total above-ground plant biomass. In the weedy and ruderal vegetation here, these two congeners with > 47 g m^{-2} above-ground biomass and about 25% importance value index, showed striking difference in their biomass allocation strategy. *S. acuta* had significantly higher leaf and branch mass fractions, reflective of its profuse branching habit and differentially higher biomass investment for photosynthetic function. In contrast, *S. cordifolia* had significantly larger reproductive mass fraction (for increased colonizability) and stem-axis biomass. The overall stem biomass was comparable, indicative of common perennial tendency for firm establishment in the alien environment. With increasing plant size, both the congeners showed a similar trend of decreasing leaf mass fraction and increasing mass fractions of support and reproductive structures. Biomass allocation was significantly influenced by species, growth phase (reproductive/vegetative) and ontogeny. Thus, the present study indicated a strategic differing pattern of biomass allocation to different plant components by the congeners *S. acuta* and *S. cordifolia* which could be attributed to their invasibility in dry tropical environments.

Index Terms- *Sida acuta*, *Sida cordifolia*, invasiveness, plant-traits, species diversity

I. Introduction

Alien plant invasions have become a serious environmental problem and have posed a grave threat to native biodiversity all over the earth ecosystem [1]. The anthropogenic interventions in tropics, as a result of increasing human population and improved trans-continental transport, can be considered to have significantly contributed to the increasing pressure of the invasive species here. The peri-urban vegetation in Indian dry tropics has been reported to be infested with a considerable number of alien plant species [2, 3]. Commonly, these invasive alien plants grew aggressively and formed monocultures e.g. *Parthenium hysterophorus, Ageratun conyzoides* [4, 5] by outcompeting native plants. Such invasive alien species are well known for their ability to alter species composition, structure and function of invaded ecosystems, and have caused huge environmental damage and economic loss worldwide [6]. Identifying the factors and plant traits that contributes to the success of invasive plants is very important for predicting and controlling potentially invasive plants, and it becomes further important in the light of the fact that the mechanisms underlying invasiveness are still not well elucidated [7-9].

The ability to differentially allocate biomass to its different organs has been attributed to the considerable success of invasive plants in dry tropics [10]. Some workers have reported that successful invasive species allocated more biomass to leaves and less to roots than native species [11, 12]. This pattern of biomass allocation may promote irradiance capture, which may not be a growth deterrent under dry tropical conditions, but, it may impair water and nutrient absorptions, indicating that invasions may be environment dependent. Thus, environmental conditions must be taken into consideration while identifying the traits contributing to invasiveness. It has been suggested that successful invasive species must either use limiting resources more efficiently than native species or use them selectively at times when they are unavailable to the latter, provided life history traits are similar between invasive and native species [13]. In addition, phylogenetic relatedness of invasive and similarity of ecological conditions should also be taken into account and the comparisons of traits across these could be a powerful approach to evaluate the invasiveness of alien plants [7, 8, 14].

Identification of the traits that are associated with invasiveness of alien species is often considered useful for better prediction of the potential of invasive species before introduction or for their control in the existing environment [15]. The present work was undertaken to understand the characteristic invasibility of two common alien congeners of *Sida* (family Malvaceae) in peri-urban vegetation in Indian dry tropics in terms of their differential biomass allocation pattern. *Sida acuta* Burm f. frequently dominates improved pastures, waste and disturbed places roadsides [16]. The plant is native to Mexico and Central

America but has spread throughout the tropics and subtropics [17]. *Sida cordifolia* L. is commonly known as Indian ephedra because of the presence of alkaloid ephedrine. This plant is native of tropical and subtropical part of Africa, Australia, China, Nepal, Sri Lanka, Bhutan and Pakistan [18]. While *S. acuta* is considered as an exotic invasive weed in India [19-21], *S. cordifolia* is a naturalized/invasive weed here [19].

The major objective of this work was to investigate: (i) the structure of *Sida*-infested vegetation in a dry tropical peri-urban anthropo-ecosystem, and (ii) variation of morphological traits and allocation of biomass to different above-ground components in the congeners *Sida acuta and Sida cordifolia* at a site.

II. Material and Methods

Study area

The present study area was Bulandshahr (28º04' & 28º43' N lat. and 77º08' & 78º28' E long.) located at distance of 72 km from Delhi in the western part of Uttar Pradesh, 237.44 m above sea level. The district of Bulandshahr lies between Ganga and Yamuna rivers. It is about 84 km in length and 62 km in breadth. The district is known as 'milk belt' of UP. The soil of the district includes broad belt of excellent alluvial soils formed from depositions by the Ganga and Yammuna river. The Bulandshahr city shares common boundaries with Meerut, Ghaziabad, Gautam Budh Nagar (Noida) and Aligarh city on its various sides. The Ganga separates it from Moradabad and Badaun city and Yamuna separates the city from Haryana state and Delhi.

The vegetation here mainly comprised of mosaic of annual weeds and ruderals. Several exotic weeds intruded in this area included *Sida* and its congeners. Bank of polluted Kali (black) river (KRB) was selected that witnessed abundant growth of *Sida acuta* and *Sida cordifolia*. This river originates in Muzaffarnagar and after a long journey merges with Ganga in Farukhabad district. This KRB site witnessed the intensive dumping of urban and sewage wastes. Agricultural fields, however, lay along its banks in the adjoining areas. A stretch of 2 km along the bank of the Kali river was selected for intensive sampling in this study.
The climate of the study area has three major seasons: rainy (Jul-Oct), winter (Nov-Feb) and summer (Mar-Jun). The mean maximum and minimum temperature was in the month of June (41.5 ºC) and January (8.0 ºC) respectively. Annual mean rainfall was 642.3 mm received mostly during monsoon (Jul-Oct).

Plant sampling

The phytosociological data analysis of the study site was done through a total of 50 randomly laid quadrats (each 25 × 25 cm) across the bank of Kali river. For density estimation of grasses, every emergent tiller was considered as one individual. Above-ground biomass (AGB) was estimated through ground level harvesting. The aboveground tissues were considered to be within the quadrat, if their roots lay in the quadrat. In the laboratory, the plant samples were washed, dried at 60-80℃ for 36-48 hrs and weighed. The above-ground biomass of species was used as a dominance measure. Importance value index (IVI) of each species was calculated according to Curtis and McIntosh [22] and relative importance value index (RIVI) as IVI/3 according to Risser and Rice [23].

Species diversity

Species IVI was plotted against species rank (highest to lowest) [24] for the study of the dominance diversity structure of the vegetation under study.
α diversity of the vegetation (species count, Shannon-index, Simpson index) was estimated according to Magurran [25] and Gupta and Narayan [26]. β diversity was estimated by dividing the total number of species at the site by the average number per sample [27].

Biomass sampling of *Sida* congeners

Eighty individuals of each of the two species *Sida acuta* and *Sida cordifolia* were randomly selected from the study site (KRB). The plant individuals were picked at varying stages of their growth. The selected individuals were cautiously clipped off from the plant base. Shoot length (SL) of the fresh individuals was measured from the top to bottom of the plant at the study site. Basal diameter of all plant individuals was also measured. All plant individuals were taken to lab, separated into different above-ground components *viz.* stem (stem-axis and branch), leaves and reproductive parts (flowers and capsules), oven-dried at 80̊ C for 48 hrs and weighed. Biomass allocation to different components was characterized by fractions (stem-axis mass fraction, SAMF; branch mass fraction, BMF; stem (stem-axis + branches) mass fraction, SMF; leaf mass fraction, LMF and reproductive part (flowers + capsules) mass fraction, RPMF), expressing the biomass of each organ relative to that of the total above-ground biomass.

One hundred fresh leaves of matured plant individuals were randomly collected from study site. Leaf area of all leaves was measured by digital leaf area meter (Systronics).

Statistical analysis

The relation of plant's above-ground component mass fractions (stem mass fraction; SMF, leaf mass fraction; LMF and reproductive part mass fraction; RPMF) to total above-ground biomass (log scale) was studied. A linear regression model was used to evaluate the biomass allometric relationships between each component mass fraction and total above-ground biomass [28]. To determine the biomass allocation changes with increasing plant size, all aboveground component mass fractions (SAMF, BMF, SMF, LMF and RPMF) were regressed against shoot length. For this, a second order polynomial regression model was used. The difference in the morphological traits of plants was statistically (SPSS 17.0) examined by t-tests (two tailed).

All plant individuals were separated over two developmental phases (reproductive and vegetative). Contribution of biomass to different above-ground components by *S. acuta* and *S. cordifolia* was compared at both developmental stages. With the help of two-way ANOVA (SPSS 17.0), effect of phase, species and their interaction on dependent variables (SAMF, BMF, SMF, LMF and RPMF) was measured keeping phase and species as fixed factors.

III. Results

Vegetation structure

A total of 27 angiospermic plant species distributed over 11 families were recorded in this study. Poaceae, Malvaceae and

Table 1. Plant species, their density (D, individuals m^{-2}), frequency (F, %), above-ground biomass (AGB, g m^{-2}) and relative importance value index (RIVI) at Kali river bank site in a dry tropical peri-urban region.

Species	**Family**	**D**	**F**	**AGB**	**RIVI**
Cynodon dactylon (L.) Persoon	Poaceae	248	84	28.9	17.0
Sida acuta Burm F.	Malvaceae	151	100	39.1	15.6
Digitaria adscendens (Kunth) Henrard	Poaceae	121	84	18.6	10.3
Parthenium hysterophorus L.	Asteraceae	51	92	27.8	9.5
Sida cordifolia L.	Malvaceae	67	100	8.4	6.9
Malvastrum tricuspidatum (R. Br.) A. gray	Malvaceae	67	74	11.2	6.7
Peristrophe bicalyculata (Retz.) Nees	Acanthaceae	34	84	5.7	4.7
Cassia obtusifolia L.	Leguminosae	14	66	12.1	4.6
Dactyloctenium aegypticum (L.) P. Beauv.	Poaceae	44	58	7.0	4.6
Cassia occidentalis L.	Leguminosae	5	58	8.9	3.4
Abutilon indicum (L.) Sweet	Malvaceae	8	66	4.3	3.0
Croton bonplandianum Baillon	Euphorbiaceae	5	66	1.9	2.4
Poa annua L.	Poaceae	10	34	3.5	1.9
Acrachne racemosa (Roemer & Schultes) Ohwi	Poaceae	9	34	1.5	1.6
Others (13 species)	-	29	-	10.4	7.9

Leguminosae were the dominant families which contributed to 56% of the recorded flora. *Sida acuta* was the most dominant annual forb in this vegetation that showed highest plant biomass occupancy (39.1 g m^{-2} AGB) (Table 1). Both congeners *S. acuta* and *S. cordifolia* showed presence across all randomly sampled quadrats (Frequency 100%), AGB > 47 g m^{-2} and contributed to about 25% of total RIVI of the vegetation. The second most frequently encountered flora was *Parthenium hysterophorus* (> 90%). The third congener *Sida ovata* occupied 17th rank in terms of RIVI. However, the most dominant species in terms of RIVI was the grass flora *Cynodon dactylon* (RIVI 17.0).

Species diversity in terms of Shannon index was 1.16, Simpson index 0.09, and β diversity was 2.31. The dominance-diversity curve indicated a major share of resource between *Cynodon dactylon*, *Sida acuta* accounting for > 32% of RIVI followed by *Digitaria adscendens* and *Parthenium hysterophorus* that accounted for about 20% of RIVI (Figure 1). A meagre share of resource was equitably distributed among the majority of tail-ending species.

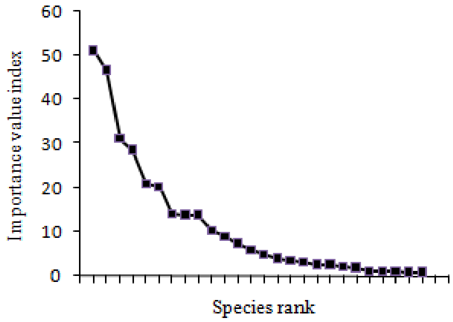


Figure 1. The dominance-diversity structure of vegetation at Kali river bank site in a dry tropical peri-urban region

Plant level traits

The mean stem-axis biomass of *S. Cordifolia* was significantly higher than that of *S. acuta* ($p < 0.05$) (Table 2). In contrast, the number of branches and branch mass fraction (BMF) was higher in *S. acuta*. The number of leaves as well as leaf mass fraction (LMF) was also higher in *S. acuta*. However, the leaf biomass per leaf was higher for *S. cordifolia*. In contrast to BMF and LMF that were higher in *S. acuta*, RPMF was recorded higher for *S. cordifolia* ($p < 0.001$).

The biomass partitioning to leaves (LMF) and reproductive parts (RPMF) differed significantly with the change of species of *Sida* in the present study (Table 3). The variation in SAMF, SMF and LMF appeared significantly influenced by growth phase (vegetative and reproductive). The SMF was also influenced by species-phase interaction ($p < 0.001$).

Allocation pattern

Biomass investment to different plant components in both *S. acuta* and *S. cordifolia* varied with vegetative/ reproductive phase of development (Fig. 2). In vegetative phase of *S. cordifolia*, SAMF and BMF together accounted for over 50% of its total AGB. On the other hand, in *S. acuta* the leaf component alone accounted for over 60% of its total AGB. In reproductive phase *S. acuta* contributed more to branches (22%) and leaves (32%) while *S. cordifolia* invested more to reproductive parts (30%).

Table 2. Plant-level traits (mean ± SE) of *Sida acuta* and *Sida cordifolia* in a dry tropical peri-urban region.

Traits	***S. Acuta***	***S. cordifolia***	**p value (t Test)**
Shoot length (SL) (cm)	28.90 ± 2.52	27.63 ± 2.54	ns
Basal diameter (BD) (cm)	0.42 ± 0.04	0.40 ± 0.03	ns
Basal area (BA)	0.22 ± 0.04	0.17 ± 0.02	ns
BD/SL ratio	0.016 ± 0.001	0.019 ± 0.001	< 0.01
Branch no.	13.32 ± 0.93	10.64 ± 0.72	< 0.05
Total leaf no.	167.28 ± 30.38	99.9 ± 15.15	≤ 0.05
Total no. of flowers	183.35 ± 41.10	148.95 ± 25.37	ns
Total no. of capsules	180.85 ± 46.85	117.17 ± 25.91	ns
No. of rep parts (flowers + capsules)	273.78 ± 62.87	251.48 ± 46.56	ns
Stem-axis biomass (g)	1.31 ± 0.28	2.53 ± 0.53	<0.05
Branch biomass (g)	2.54 ± 0.65	1.41 ± 0.49	ns
Stem biomass (g)	3.34 ± 0.78	3.03 ± 0.69	ns
Leaf biomass (g)	1.26 ± 0.19	1.10 ± 0.20	ns
Single leaf biomass (g)	0.008 ± 0.001	0.012 ± 0.001	<0.001
Reproductive part biomass (g)	2.00 ± 0.52	3.27 ± 0.66	ns
Shoot biomass (AGB) (g)	5.61 ± 1.23	5.76 ± 1.23	ns
Stem-axis mass fraction (SAMF)	0.27 ± 0.01	0.31 ± 0.01	ns
Branch mass fraction (BMF)	0.23 ± 0.02	0.12 ± 0.01	<0.001
Stem mass fraction (SMF)	0.41 ± 0.02	0.41 ± 0.02	ns
Leaf mass fraction (LMF)	0.52 ± 0.03	0.39 ± 0.03	<0.01
Rep part mass fraction (RPMF)	0.14 ± 0.02	0.25 ± 0.02	<0.001
Leaf area (cm^2)	6.18 ± 0.57	7.56 ± 0.75	ns

Table 3. Results of the ANOVA of the different above-ground biomass components of *Sida acuta* and *Sida cordifolia* in response to their vegetative and reproductive phases.

Variable	**Source**	**df**	**Sum of sq**	**F**	**P**
SAMF	Species	1	0.056	2.455	0.119
	Phase	1	0.096	4.188	0.042
	Interaction (species × phase)	1	0.021	0.931	0.336
BMF	Species	1	0.007	0.503	0.48
	Phase	1	0.005	0.368	0.545
	Interaction (species × phase)	1	0.133	9.694	0.002
SMF	Species	1	0.011	0.827	0.364
	Phase	1	1.093	85.123	<0.001
	Interaction (species × phase)	1	0.184	14.326	<0.001
LMF	Species	1	0.101	5.726	0.018
	Phase	1	5.287	300.416	<0.001
	Interaction (species × phase)	1	0.0001	0.004	0.949
RPMF	Species	1	0.353	32.94	<0.001
	Phase	1	-	-	-
	Interaction (species × phase)	1	-	-	-

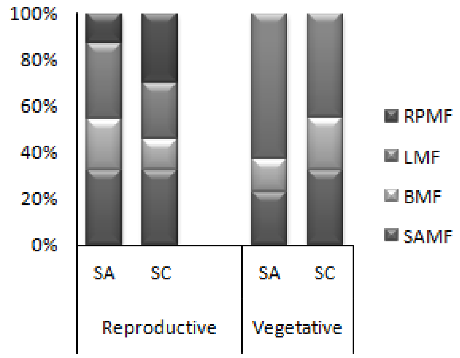
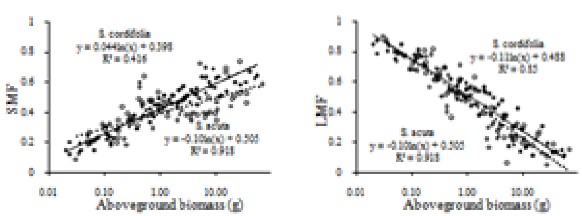


Figure 2. Biomass alloaction to different above-ground components by *Sida acuta* and *Sida cordifolia* at two different developmental phases (reproductive and vegetative). Codes: SAMF, stem-axis mass fraction; BMF, branch mass fraction; LMF, leaf mass fraction; RPMF, reproductive part mass fraction; SA, *Sida acuta*; SC, *Sida cordifolia*.

The LMF declined significantly with increasing plant size of both the *Sida* congeners (Fig. 3), albeit it was higher for *S. acuta*, particularly at higher plant sizes. In contrast to decreasing pattern of LMF, SMF and RPMF increased significantly with above-ground biomass. However, at lower plant size, SMF was higher for *S. cordifolia* while at higher plant sizes, it was higher for *S. acuta*. Compared to the SMF and LMF, RPMF was significantly greater ($p < 0.001$) for *S. cordifolia*.



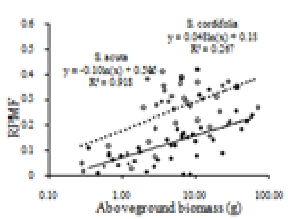


Figure 3. Allometric relationships between plant component mass fractions (stem mass fraction, SMF; leaf mass fraction, LMF and reproductive part mass fraction, RPMF) and total above-ground biomass (log scale) of *Sida acuta* (filled squares and solid line) and *Sida cordifolia* (open circles and dotted line) at Kali river bank site in a dry tropical peri-urban region.

The allometric relationship among the different above-ground plant components were studied by regression equation of second order polynomial (figure 4). Despite LMF being higher in *S. acuta* compared to *S. cordifolia*, both the weed species showed a comparable declining trend with ontogeny. The SMF increased with plant size in both the species although the increase was recorded to be higher for *S. acuta* in the mid of the growth stages. However, the reproductive allocation (RPMF) was significantly higher in *S. cordifolia* compared to *S. acuta*.

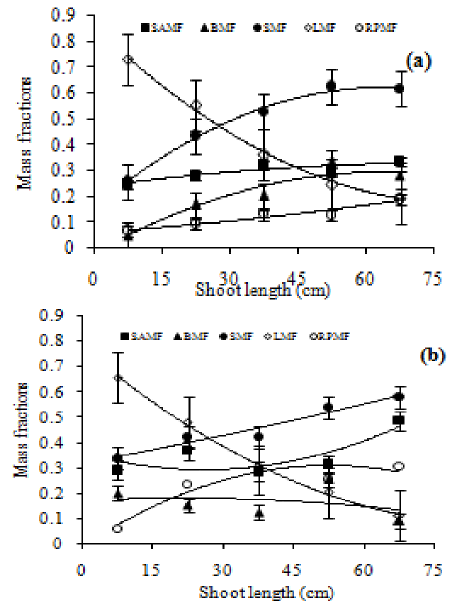


Figure 4. Variation of stem-axis mass fraction (SAMF), branch mass fraction (BMF), stem mass fraction (SMF), leaf mass fraction (LMF) and reproductive part mass fraction (RPMF) in relation to shoot length of (a) *Sida acuta* and (b) *Sida cordifolia* at Kali river bank (KRB) site in a dry tropical peri-urban region. Curves represent best-fit second-order polynomial regression.Regression equations and R^2 values are presented in table 4.

IV. Discussion

A discerning difference in biomass allocation strategy in the congeners *S. acuta* and *S. cordifolia* with strong perennial tendency was evident from this study in the weedy and ruderal vegetation along the bank of polluted Kali river in the Indian dry tropical region. The mosaic of vegetation in the presently studied peri-urban region [26] indicated occurrence of variously dominated weeds in different patches of vegetation, some of which are turning invasive and some naturalized/invasive. This increasing dominance of *Sida* congeners, particularly *S. acuta* in the studied peri-urban vegetation indicated its growing influence across the various anthropo-ecosystems in the peri-urban region here.

The major invasive characteristic of *S. acuta* could be attributed to its larger leaf number as well as allocation to leaf component (> 50%), that possibly allowed it to outcompete other incumbent weeds/ruderals through its presumably higher

Table 4. Regression equations and R^2 values of stem -axis mass fraction (SAMF), branch mass fraction (BMF), stem mass fraction (SMF), leaf mass fraction (LMF) and reproductive part mass fraction (RPMF) with shoot length of *Sida acuta* and *Sida cordifolia* at Kali river bank (KRB) site in a dry tropical peri-urban region, as presented in figure 4.

Species	Regression equation	R^2 value
S. acuta	SAMF = -2E-05x^2 + 0.002x + 0.232	0.778
	BMF = -8E-05x^2 + 0.010x - 0.027	0.920
	SMF = -0.000x^2 + 0.014x + 0.153	0.992
	LMF = 0.000x^2 - 0.017x + 0.862	0.996
	RPMF = 1E-05x^2 + 0.001x + 0.061	0.931
S. cordifolia	SAMF = 1E-04x^2 - 0.005x + 0.357	0.639
	BMF = -2E-05x^2 + 0.001x + 0.171	0.012
	SMF = 8E-06x^2 + 0.003x + 0.317	0.942
	LMF = 9E-05x^2 - 0.015x + 0.772	0.996
	RPMF = -0.000x^2 + 0.012x - 0.005	0.880

photosynthetic ability [7, 29, 30]. The remarkably higher biomass allocation to photosynthetic tissues is intelligible from the mean LMF of 0.46 reported for herbaceous species by Poorter and Nagel [31], 0.26-0.41 for herbaceous weeds in dry tropics by Gupta [2], 0.27-0.38 for invasive weeds *Chenopodium murale* [10] and *Ageratum conyzoides* [4]. Its LMF, however, declined with ontogeny although it remained higher than *S. cordifolia*, as evinced at higher plant sizes, in particular (fig. 3).

The biomass allocation to support structure was comparable in both the *Sida* congeners. However, the trend of biomass investment to main axis and branches varied significantly in these two congeners. In *S. acuta* the number of branches and differential biomass investment to branches (BMF) (reflective of its profuse branching) was significantly higher. In contrast, the biomass allocation to stem-axis was higher for *S. cordifolia*. This characteristic difference in allocation indicated a perennial tendency [10] of these two alien invasive congeners for successful establishment and naturalization in this dry tropical region. The overall stem allocation (SAMF + BMF) was not significantly different. Thus, the growth strategy of greater biomass investment to stem component for firm establishment in the newly invaded area can be attributed to the perennial tendency of this herbaceous weed to shrubby life-form, as reported by some taxonomic workers in the neighbouring regions [32, 33]. The SMF of these two congeners compared well with the range reported for the herbaceous weeds in the region [10], but higher than that reported for herbaceous species [31].
Besides higher stem-axis allocation in *S. cordifolia*, single leaf biomass and reproductive allocation (RPMF) were also significantly higher. Thus, pronounced invasive character of *S. cordifolia* could be attributed to higher biomass investment to reproductive structures [34, 35]. This alien weed is reported to have higher number of seeds (~10 /capsule) compared to *S. acuta* (5-8 /capsule) [36] and seed size as observed in this study. Reproductive allocation to the scale of 30% of its total AGB corroborates its strategic invasive and expansionist capacity [10].

The study reflected shift in allocation strategy varying with the growth phase, species type and ontogeny. This indicates a high plastic response of the congeners of *Sida* that facilitated its adaptation and establishment under alien environments. With increasing plant size, while LMF declined on one hand SMF and RPMF increased with the other. Across different plant sizes over varying developmental stages, the higher RPMF for *S. cordifolia* at all ontogenetic points and higher LMF for *S. acuta* reflected a distinguishable difference in their invasive growth strategy. Different plant-traits are often suggested to promote invasiveness of different species, as a universal syndrome of traits to characterize all invasive species appears too simplistic [37-40].

In conclusion, the study reflected a strategic alteration in biomass allocation to different plant components by the congeners *S. acuta* and *S. cordifolia.* While *S. acuta* allocated differentially higher biomass to photosynthesizing leaf component, *S. cordifolia* allocated relatively higher biomass to reproductive structural components. Biomass allocation varied with ontogeny, growth phase (vegetative/reproductive) and plant species.

ACKNOWLEDGEMENTS

We are thankful to the University Grants Commission, New Delhi, for financial support. We are also grateful to the contribution of late Dr. L. K. Sharma for his assistance in identifying plant species. Anonymous reviewers are also thanked for their comments and fruitful suggestions.

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