EXOTIC INVASIVE *AGERATUM CONYZOIDES* L. IN INDIAN DRY TROPICS: A PRELIMINARY INVESTIGATION OF ITS BIOMASS ALLOCATION PATTERN AND PLANT TRAITS

Nidhi Chaudhary and Rup Narayan

Department of Botany, I. P. (PG) College, Bulandshahr- 203001, Uttar Pradesh
E-mail-nidhi.c06@gmail.com

Abstract: Billy goat weed *Ageratum conyzoides* was investigated for its biomass allocation pattern and plant traits across two contrasting soil resource regimes in a peri-urban region in Indian dry tropics. The plant populations at low resource (LR) site showed higher root length, biomass of root, leaf and reproductive parts and their mass fractions. High resource (HR) site showed higher shoot length and stem mass fraction. Plasticity indices of root mass fraction, root:shoot length and biomass ratios were higher at LR site. Phenotypic plasticity was also higher here. Biomass allocation to different components varied with ontogeny and soil resource states. Higher reproductive and root allocation by *Ageratum conyzoides* at LR site can be attributed to its successful invasive character in this region.

Keywords: Biomass allocation, Plant component biomass, Phenotypic plasticity, Bulandshahr

INTRODUCTION

Ageratum conyzoides L. is widely spread the world over, especially in the tropical and sub-tropical region including India (Singh *et al*. 2013). Commonly known as Billy goat weed, this plant species has been considered medicinally important for its wide pharmacological uses (Okunade 2002). However, its rapid colonization ability and expansion into the newer habitats and gradual establishment particularly in tropics (which houses the largest biodiversity of the globe) through displacement of the indigenous flora, and subsequent effects on ecosystem health, has been the growing ecological concern to land managers, conservationists and government agencies here (Gupta & Narayan 2006, 2012). Invasions by such species have been increasingly recognized as a significant component of human-caused global environmental change, that often modify the functioning of invaded ecosystems (Mack *et al*. 2000). Such invasions are likely to be more apparent in and around urbanizing landscapes with a variety of land uses that creates environment conducive for invasion by weeds (McKinney 2002; Turner *et al*. 2004) especially the alien ones. The global recognition of adverse impact of invasion by exotic plant species leading to ecosystem alteration, threatening the integrity of agricultural and natural systems (Simberloff 2003) has been advancing consistently. Despite this, the empirical understanding of the impacts and mechanisms of exotic plant invasion remains highly rudimentary and fragmented and this is further complicated by species and site-specific effects (Callaway & Aschehoug 2000).

Phenotypic plasticity is reportedly considered as an important plant trait associated with invasiveness of alien plants that reflects its ability to occupy a wide range of environments (Droste *et al*. 2010). Variation in the ecologically important trait of a species, such as biomass allocation pattern, could facilitate the evolution of greater plasticity and invasiveness. Accordingly, differing biomass allocation strategy is likely to be met with environmental changes (Bloom *et al.* 1985, Zhao *et al.* 2010, Gupta & Narayan, 2012).

The menace of invasive aliens has been recognized immensely in India too (Raghubanshi *et al*. 2005). A large number of invasive aliens in U.P. have been reported to be introduced unintentionally through trade exchanges (Singh *et al*. 2010). Of these exotic invasives in India, *Ageratum conyzoides* has been increasingly observed as a rapid colonizer across diverse peri-urban anthropo-ecosystems in Indian dry tropics (Gupta & Narayan 2012). Several studies have been carried out on this species pertaining to its pharmacological, biochemical and ethnobotanical aspects (Singh *et al*. 2013, Okanade 2002). However, the investigative information on its ecological aspects related to its invasiveness is generally lacking, particularly in Indian dry tropics. The present work aims to understand its growth strategy in relation to its invasive ability in Indian dry tropical peri-urban ecosystems.

The major objective of the present study was investigation of the plant-level traits and biomass allocation strategy of *Ageratum conyzoides* across contrasting resource regimes in a dry tropical region.

MATERIAL AND METHOD

Study area

The study area was located at Bulandshahr ($28^0$04' & $28^0$43' N lat. and $77^0$08' & $78^0$28' E long.), western part of Uttar Pradesh which falls within Ganga basin, India. The vegetation, here, is mainly comprised of mosaic of annual weeds and ruderals (Gupta & Narayan 2010). Two study sites representing contrasting resource and habitat conditions were selected for the present study. The first site was located near Gang Nahar canal along Khurja road. This site was relatively species-rich and was not frequently visited/disturbed by humans/grazing animals. The second site represented a mosaic of

vegetation stands that mainly comprised of various annual weeds in the vicinity (100 m) of railway track. This site witnessed considerably high interference of humans and grazing animals. These two sites were designated as high-resource (HR) site, near Gang Nahar canal and low-resource (LR) site, near Railway track, based on the physico-chemical characteristics of the site-soils.
The climate of the region and the study area was semi-arid.

Soil analysis

Eight samples of surface-soils (0-10 cm) were randomly collected from each site in the months of February, May and October. The soil samples were air-dried and sieved in a 2 mm sieve. Physico-chemical properties of soils estimated in this study included soil moisture content, pH, total Organic Carbon (Walkley and Black method), total N (micro-Kjeldahl's method) according to Piper (1944); available Phosphorous and exchangeable Potassium according to Allen *et al*. 1986. Various micro-nutrients like available Sulphur, Zinc, Iron, Magnesium and Copper were estimated at the District soil testing lab in Bulandshahr, according to Piper (1944).

Plant-level measures

A total of one hundred individuals of *Ageratum conyzoides* were selected at different points of their growth, 50 from each study site (HR and LR). The selected individuals were carefully dug out of the ground with utmost care to minimize the loss of roots. This was accomplished by digging below to the root-system in a cylindrical manner approximately equal to the diameter of the top growth around the base of the plant to retrieve the smaller roots so as to make the root-loss minimum (Mahoney & Kegode 2004). They were then washed off with water carefully to remove soil particles. Shoot length (SL) of the fresh individuals was measured from the top of the plant to the point of discoloration, indicating the soil surface. In the similar way, root length (RL) was measured from the top of the root-system to the point of discoloration. Basal diameter of the plant individuals was also measured. Plants were separated into different components like leaves (petiole and lamina), stems, reproductive (inflorescence/peduncle, bud, flower and fruit) and roots. They were then oven-dried at 80ºC for 48 h and weighed to determine component biomass, aboveground (AGB), belowground (BGB) and total biomass (TB). The component mass fractions (leaf mass fraction, LMF; stem mass fraction, SMF; reproductive mass fraction, RPMF; and root mass fraction, RMF) were estimated as the biomass of each component relative to the total biomass.

Plasticity indices and statistical analysis

The variation of plant component biomass (root, leaf, stem, and reproductive parts) was studied in relation to the total plant biomass (TB). Biomass allometric relationships between each component biomass and total plant biomass were assessed through statistical methods described by Mead & Curnow (1983).
To compare the degree of plasticity among mature individuals (in reproductive phase) at two sites, a plasticity index (PI□) was generated for each trait (Valladares *et al*. 2006). The index ranges from zero (no plasticity) to one (maximum plasticity). It is evaluated as the difference between the maximum and minimum values of the trait divided by the maximum value at a site. The mean plasticity indices for plant- traits were evaluated for each species by averaging all variables. Pearson product–moment correlation coefficients were generated to evaluate the linear association between traits and total biomass of a plant individual across the study sites. Statistical and graphical analyses were carried out using MS Excel and SPSS 20.

RESULT
Species traits

On the mean basis, shoot length of plant individuals of *Ageratum conyzoides* at HR site was significantly higher (P < 0.01) compared to that at LR site. In contrast, the root length of the plants at LR site was higher. Amongst the different organal biomass components, the plant individuals at LR site showed significantly higher biomass of leaf, reproductive parts and root (P < 0.001) compared to those at HR site (Table 1). At this nutrient poor site, the total number of leaves/per plant and total plant biomass were also higher. In terms of mass fractions LMF and RPMF of *Ageratum conyzoides* at LR site was higher. On the other hand, SMF at HR site was significantly higher (P <0.001). However, RL/SL ratio and number of nodes, and stem biomass tended to be similar at both LR and HR sites (difference ns).

Plasticity indices

The plasticity index (PI_V) for both the sites (HR and LR) was calculated, which ranged between 0.66 and 0.99 for plant-level traits (Table 2). At HR site, plasticity indices for LMF and RPMF were higher than those at LR site. However, plasticity indices for RL/SL, Root/Shoot biomass ratios, SMF and RMF for plant individuals were higher at LR site. The mean phenotypic plasticity at LR site was marginally higher (PI_V 0.89) than HR site (0. 85).

Soil characteristics

The soils at HR site showed higher moisture content, total Nitrogen and Organic Carbon (%) compared to

LR site-soils (Table 3). However, available P, S, Zn, Fe, Mg, Cu and exch. K were comparable at both sites.

Relationship between various traits and total plant biomass

Total biomass showed strong and positive correlations with SL, RL, Basal diameter, and biomass of leaf, stem reproductive parts and root at both HR and LR sites. However, RL/SL ratios, Root/Shoot biomass ratios and LMF had negative correlations (Table 4). The Root/Shoot biomass ratios and LMF at HR site were not significantly correlated. Similarly, at LR site, the RL/SL ratio did not show significant interrelations.

Biomass allocation pattern

The plant individuals at LR site showed relatively higher biomass allocation to leaf, reproductive parts and root components compared to HR site (Fig. 1). However, the general trend of stem allocation is same/similar at both sites.

DISCUSSION

Ageratum conyzoides is a seasonal weed in Indian dry tropics. However, as evinced in the present study, with its limited temporal growth here, this exotic weed exhibited remarkable capacity to cope up with diverse resource regimes. This can be visualized as an altered growth strategy for optimization of growth across diverse environmental conditions, allowing its naturalization in alien land and intrusion into newer habitats, which is an essential characteristic for plant to be invasive (Jiang *et al* 2011).

The range of biomass allocation to leaf in this study compared well with that reported for *Chenopodium murale* (0.28 – 0.35) (Gupta and Narayan 2012) recorded across two contrasting resource regimes, although it was lower than that reported by Poorter and Nagel (2000) (mean LMF 0f 0.46) for herbaceous plants. However, the trend across the habitat-stress conditions was different in this study. While *Chenopodium murale* allocated more at HR site, *Ageratum conyzoides* allocated more at LR site. Thus, despite both being exotic invasive weeds in this dry tropical peri-urban region, they appear to exhibit differing biomass allocation strategy in relation to soil resources.

Comparatively higher allocation of biomass to root, leaf and reproductive parts by *A. conyzoides* at LR site indicated its superior competitive ability under nutrient-stress conditions. A significantly high reproductive allocation here appears to have greatly contributed to production of large number of seeds, thus resulting into its high colonization ability and concomitant spread to newer areas and facilitating its invasiveness (Richardson *et al*. 2000). The higher root length and enhanced root allocation at LR site can be suggestive of developing larger nutrient absorption organs for optimum growth (Hernández *et al*. 2010; Műller *et al*. 2000; Wu *et al*. 2008), particularly under dry-tropical conditions. The increased root production at LR site is often suggested to allow plants to take up dispersed resources (Burke 2005; Sui *et al*. 2011). On the other hand higher leaf allocation is indicative of higher photosynthetic potential of the plant individuals here. Thus, *Ageratum conyzoides* appears to efficiently utilize both above-ground and below-ground resources. The marginally higher mean plasticity index at LR site indicates its higher ability of morphological modification in response to altered edaphic resources (as evinced by higher plasticity index for RMF, SMF, RL/SL and root/shoot biomass ratios).

The higher SMF and shoot length by plants at HR site indicated differentially high stem allocation for firm establishment and optimum use of above-ground resources (Pyšek & Richardson 2007).

The allometric analyses in the present study revealed shift in allocation of biomass in different organs, as the plant grew and matured. Although, the biomass of each component was significantly related to total biomass of the plant, the nature of relation varied. While the root and leaf were negatively related, stem and reproductive parts had positive relation. This indicated that there was greater biomass investment to root and leaf at the initial stage of their development that decreased with size (King 2003). This ontogenetic variation in biomass allocation makes assessment of the influence of resource state difficult. This, however, can be better assessed when the allocation at two resource states is compared at the same ontogenetic point (Gupta & Narayan 2012).

In conclusion, this study revealed that biomass allocation varied with ontogeny as well as in response to soil resource conditions and invasive ability of *Ageratum conyzoides* could be attributed to its enhanced reproductive and root allocation.

Fig.1 Allometric relationships.

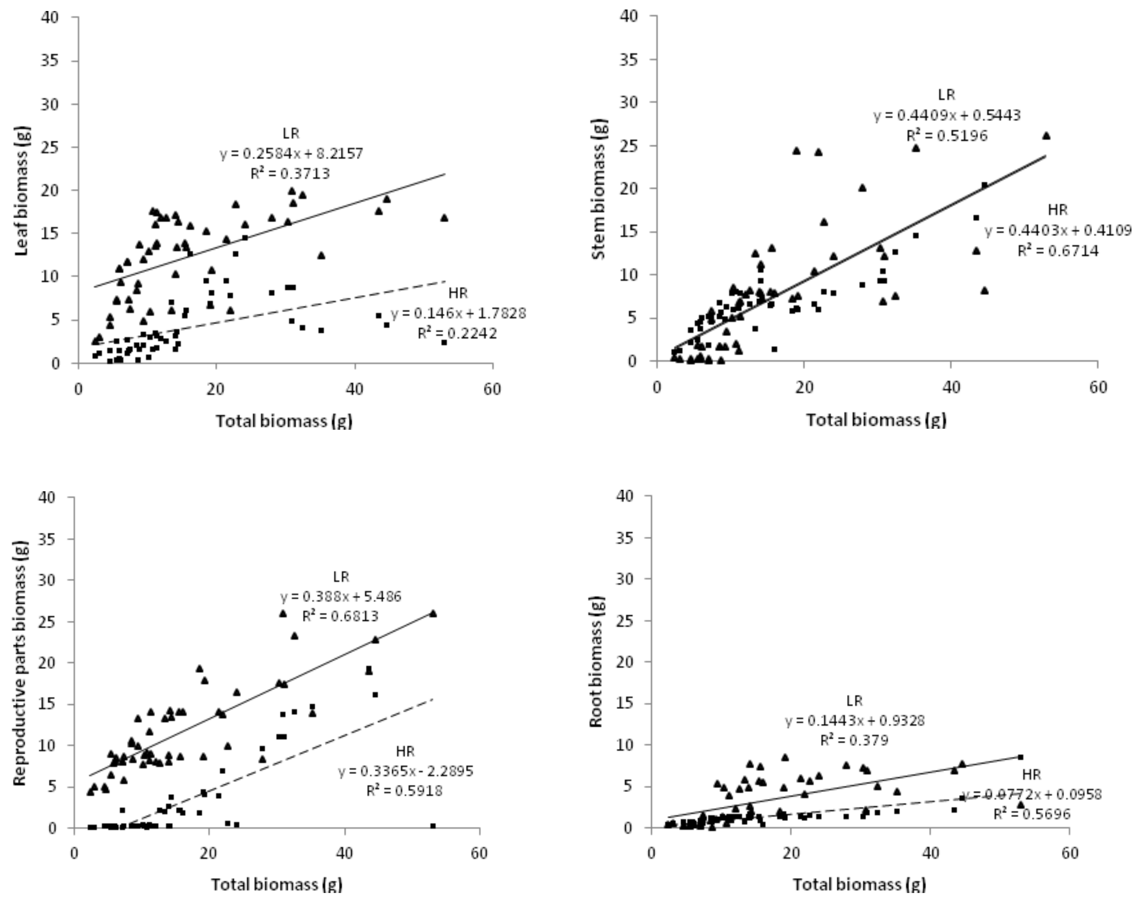

Fig. I

Table 1. Plant-level traits of *Ageratum conyzoides* (Mean ± SE) at high-resource (HR) and low-resource (LR) sites in a dry tropical peri-urban region.

Plant-Level Traits	**HR site**				**LR site**			***P* value (*t* test)**
Shoot length (SL) (cm)	87.28	±	2.61		51.08	±	2.68	< o.oo1
Root length (RL) (cm)	14.87	±	0.32		18.60	±	1.19	< 0.05
Basal diameter (cm)	0.57	±	0.02		0.74	±	0.01	< 0.001
No. of Leaves	552.00	±	62.74		799.68	±	29.78	< 0.001
No. of Nodes	15.62	±	0.73		14.50	±	0.42	ns
Leaf biomass (g)	4.10	±	0.49		12.32	±	0.67	< 0.001
Stem biomass (g)	7.41	±	0.85		7.55	±	0.97	ns
Reproductive parts biomass (g)	3.06	±	0.69		11.65	±	0.75	< 0.001
Root/belowground biomass (g)	1.32	±	0.16		3.22	±	0.37	< 0.001
Total biomass (g)	15.90	±	1.59		34.76	±	2.13	< 0.001
RL/SL ratio	0.17	±	0.01		0.40	±	0.02	< 0.001
BGB/AGB ratio	0.10	±	0.01		0.09	±	0.01	ns
Leaf mass fraction (LMF)	0.27	±	0.02		0.38	±	0.01	< 0.05
Stem mass fraction (SMF)	0.51	±	0.02		0.18	±	0.02	< 0.001
Root mass fraction (RMF)	0.09	±	0.01		0.08	±	0.01	ns
Reproductive parts mass fraction (RPMF)	0.13	±	0.01		0.36	±	0.01	< 0.001

Table 2. Plasticity indices of different plant-traits of *Ageratum conyzoides* (mature plants) at high-resource (HR) and low -resource (LR) sites in a dry tropical peri-urban region.

Traits	**HR**		**LR**
RL/SL ratio	0.66		0.93
Root/Stem biomass ratio	0.73		0.96
LMF	0.95		0.79
SMF	0.89		0.99
FMF	0.99		0.72
RMF	0.88		0.97
Mean	**0.85**		**0.89**

Table 3. Physicochemical characteristics of soils at high- resource (HR) and low-resource (LR) sites in a dry tropical peri-urban region.

Soil analysis	**HR site**				**LR site**		
Moisture Content (%)	2.37	±	0.30		1.65	±	0.05
Nitrogen	0.06	±	0.00		0.04	±	0.02
pH	7.05	±	0.06		7.39	±	0.03
Org C (%)	1.28	±	0.02		0.36	±	0.02
Available P (kg/ha)	8.87	±	0.58		8.50	±	0.37
Exch. K (kg/ha)	133.37	±	3.47		130.62	±	1.05
Available S (ppm)	11.60	±	0.16		11.31	±	0.11
Available Zn (ppm)	0.74	±	0.01		0.74	±	0.01
Available Fe (ppm)	4.97	±	0.11		4.65	±	0.04
Available Mg (ppm)	4.81	±	0.02		4.73	±	0.01
Available Cu (ppm)	0.64	±	0.01		0.64	±	0.01

Table 4. Pearson product–moment correlation coefficient (r) for relationships between various plant-level traits and total biomass for *Ageratum conyzoides* at high-resource (HR) and low resource (LR) sites in a dry tropical peri-urban region.

Plant-Level Traits		**HR site**			**LR site**
Shoot length		0.669**			0.767**
Root length		0.341*			0.450**
Basal diameter		0.348*			0.479**
Leaf biomass		0.474**			0.702**
Stem biomass		0.819**			0.801**
Reproductive parts biomass		0.769**			0.804**
Root biomass		0.755**			0.732**
RL/SL ratio	-	0.288*		-	0.257
Root/shoot biomass ratio	-	0.240		-	0.373**
Leaf mass fraction	-	0.080		-	0.514**
Stem mass fraction	-	0.358**			0.655**
Root mass fraction	-	0.446**			0.487**
Reproductive parts mass fraction		0.666**		-	0.514**

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

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