Ecological adaptation of *Eupatorium adenophorum* populations to light intensity

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Abstract: *Eupatorium adenophorum is* one of main invasive plants in China and has caused great economic losses. A study was conducted to determine the biomass allocation, leaf morphology and growth response of *E. adenophorum* seedlings that grew under five different intensities (relative irradiances *RI* 10%, 20 %, 30%, 55%, 100%) for 14 months. Results reveal that the species shows typical leaf morphological adaptation to different light conditions. The total biomass of seedlings increased with the increase of light intensity from 10% to 55% RI but decreased at RI 100% (full sunlight). Height growth increased with the increase of light intensity from 10% to 30% RI but decreased when light intensity was over 30% RI. At low light levels, plants enhanced light availability by means of increasing biomass allocation to leaves and formation of larger, thinner leaves with high specific leaf area (*SLA*), leading to a high leaf area ratio (*LAR*) and high stem strips length (*SSL*). The mean relative growth rate (*RGR*) of the plant increased with the light intensity increase and attained the maximum at 55% RI. The growth of seedlings at 30%–55% RI was much better than that at full light condition. This might be an adaptive strategy that supports the vigorous invasiveness of this species, because a high-shaded canopy could prevent other plant species from surviving and growing. This study indicates that *E. adenophorum* could adapt to different light conditions, especially to low light habit. This can explain its greater invasiveness.

Keywords: Ecological adaptation; *Eupatorium adenophorum*; Invasiveness; Light intensity
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Introduction

Plant response to environmental change by itself morphological plasticity that descends from plant growth. The capability of relative transfer makes selection to the habit (Kroon *et al.* 1995; Sutherland *et al*. 1988; Kelly *et al*. 1990; Cain 1994). The plant develops the characteristic of foraging behavior by altering individual growth habit with the change of resource in the environment. In other words, the foraging behavior of plant depends on its morphological plasticity in the term of heteroplasmic resource (Shan *et al.* 2000.). Therefore, the morphological plasticity of plant predicates its adaptation to the environment (He *et al.* 1999).

One important strategy of plant adapting to different environment and resource is the change of morphological characteristics and growth character (Maherali *et al*. 2001; Müller. *et al.* 2000). Light is one of the most important ecological factors affecting plant growth, which has significant effect on plant growth, development and evolvement (Bazzaz 1996; Poorter 2001; Feng *et al.* 2002; Larcher *et al.* 1995; Bazzaz *et al.* 1996). It is usually found that heliophililous plant extends intersegmentum length obviously and improves growth speed when it is set in overshadow, thus making newly leaf reach out of canopy to attain enough sunlight (Smith 1982; Liang *et al.* 2004). The phenomenon is called the light naturalization in terms of the growth response level.

Crofton weed (*Eupatorium adenophorum*) is one of main alien invasive plants in China now. It spread from Burma into Yunnan Province of China in 1940s. The alien invasive species disturbs mostly in Yunnan, Guizhou, Guangxi and Sichuan provinces (Li *et al.* 2002; Xu *et al.* 2004) and has brought grave impact to the ecological environment, economical development and people health (Sun 2004) of these provinces.

Materials and methods

Study area

This research was conducted in Wuben Township of Panzhihua, Sichuan Province. Wuben Township, originally named Ura, locates in the center of Panzhihua city and covers an land area of 115.6 km^2 within the geographic coordinate from 101.36–101.47E and 26.39–26.46N. In general, the physiognomy of Wuben Township is complicated. Mountainous region dominates Wuben rural area in which the western part is low and the eastern part is relatively high. It locates within the elevation of 1250–2926 m. Wuben Township belongs to the south subtropical climatic semiarid zone. The annual average temperature ranges from 15.8 ºC to 20.2ºC.

Experimental method

The seeds of Crofton weed that were collected in local area in middle August of 2003 were sown in the bed set in shade. At the beginning of October 2003, the seedlings around 15 cm height were transferred in flowerpot and cultured in shade for one week. Then, we randomly grouped the seedlings. Other factors that maybe influence growth and development of the plants are excluded. Four kinds of sunshading sheds were set, which were covered with 1 lay, 2 lays, 3 lays and 4 lays of black shadow net separately, to create the relative irradiance (RI) of 55%, 30%, 20% and 10% of total light intensity. In addition, we set plant in

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total light as contrast, i.e. 100% relative irradiance. The pots in size of 24 cm in diameter, 15 cm in height, with experimental material were used for cultivating experiment. The culturing substrate is the mixture of the surface soil that collected form 10 cm layer in forest and river sand. One week later, we measured the height, leaf area, and dry weight of supporting organs and root. Two weeks later, the same indexes are measured again. All experimental groups have 10 repeats.

The experimental seedlings were watered every three days during drought except for rainy days. Fourteen months later (December 2004), we obtained the indexes of plant height, crown area, segment length, leaf number, leaves area, leaf stalk length, and root weight. We measured individually the biomass of total plant, leaves, leaves stalk, stem, and root.

Data analysis

Plant height was measured with ruler (1mm definition) and leaf area was measured with LI-3000 Portable area meter. Dry weight was measured with electronic scale (definition 0.0001g) after the material was baked 48 h at 84℃. In this paper, we refer to the following indexes: Root mass ratio (RMR), leaf mass ratio (LMR), supporting organs biomass ratio (SBR), leaf mass fraction (LMF), leaf area ratio (LAR), leaf area root mass ratio (LARMR), root mass/crown mass (R/C), specific leaf area (SLA), mean leaf area(MLA), stem strips length (SSL), stipe leaf stalk length (SLSL), mean relative growth rate (RGR), net assimilation rate (NAR). Relative formulas are listed as follows.

$$RMR = \frac{\text{Root mass}}{\text{Plant mass}} \tag{1}$$

$$LMR = \frac{\text{Leaf mass}}{\text{Plant mass}} \tag{2}$$

$$SBR = \frac{\text{Supporting organ mass}}{\text{Plant mass}} \tag{3}$$

$$LAR = \frac{\text{Total leaf area}}{\text{Plant mass}} \tag{4}$$

$$LMF = \frac{\text{Leaf mass}}{\text{Above - ground root mass}} \tag{5}$$

$$LARMR = \frac{\text{Total leaf area}}{\text{Total root mass}} \tag{6}$$

$$RIS = \frac{\text{Root mass}}{\text{Above - ground ogans mass}} \tag{7}$$

$$SLA = \frac{\text{Total leaf area}}{\text{Total leaf mass}} \tag{8}$$

$$SSL = \frac{\text{Total stem strips length}}{\text{Total stem mass}} \tag{9}$$

$$MLA = \frac{\text{Total leaf area}}{\text{leaf amount}} \tag{10}$$

$$SLSL = \frac{\text{Total stipe leaf stalk length}}{\text{Total stipe leaf stalk mass}} \tag{11}$$

Mean relative growth rate (RGR), net assimilation rate (NAR) and mean leaf area ratio (LAR_m) are calculated according to the methods of Wang Shasheng (Wang *et al.* 1991).and Poorter (Poorter 1999).

$$RGR = \frac{\ln W_2 - \ln W_1}{\Delta t} \tag{12}$$

$$NAR = \frac{W_2 - W_1}{L_2 - L_1} \times \frac{\ln L_2 - \ln L_1}{\Delta t} \tag{13}$$

$$RGR = LAR_m \times NAR\ ,$$

So,

$$LAR_m = \frac{\ln W_2 - \ln W_1}{W_2 - W_1} \times \frac{L_2 - L_1}{\ln L_2 - \ln L_1} \tag{14}$$

Where, W_1 and L_1 indicate respectively the arithmetic mean of 5 repeat plants for total biomass and leaf area at first time. W_2 and L_2 indicate respectively total biomass and leaf area at second time.Δt indicates the interval of two times(d) (Wang *et al.* 2004).

With the software of SPSS12.0, we analysis the result by the method of analysis of variance between groups (ANOVA) and Least-significance difference test (LSD)(Lu, D.W. 2000).

Results and analysis

The effect of light intensity on total biomass and plant height of Crofton weed

The total biomass of Crofton weed in 5 groups has significant difference. Total biomass increases with the increase of light intensity within the scope of 10%–55% RI, but it decreases in full sunlight (Fig1-I). This result agrees with Wang and Feng's (2004) conclusion and is similar to Poorter's (2001) research on tropical trees. Height growth increases with the increase of light intensity from 10% to 30% RI but decreases when light intensity is over 30%RI (Fig. 1-II). Seen from Fig. 1-I and II, Crofton weed grow well in certain shadow. Stem strips length of Crofton weed gradually increases with the decrease of light intensity (Fig. 1-III). The change helps plant to prolong stem per unit biomass, thus plant can adapt to the environment change by adjusting morphological plasticity by itself. The relative mobile ability of plant reflects plant foraging behavior in the condition of heterogeneous environment.

The effect of light intensity on biomass allocation of Crofton weed

Under the condition of full sunlight, the biomass allocation pattern of Crofton weed seedling to each organ is as stem >root >leaf >leaf stalk. However, with the decrease of light intensity, the biomass allocation of the seedling to leaf is more than to root, and the biomass of leaf stalk is also increased (Fig 2-VIII). During fluctuation of RI from 10%–100%, root mass /crown mass has significant difference (P<0.01) (Fig. 2-II). It decreases with RI decrease, which indicated that when light is limited the biomass allocation to root decreases while that to above-ground increases, i.e. plant suction tension decreases. The phenomenon can be reflected by leaf area root mass ratio (LARMR) (Fig.2-III). Significant difference (p<0.05) of LARMR in different groups indicates that the ecological strategy inclined to increasing the investment to total leaf and decreasing the investment to root.

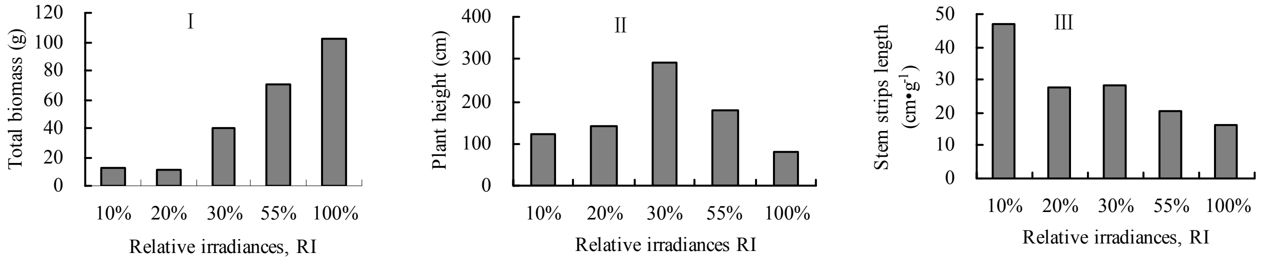

Fig.1 The total plant biomass, height, and SSL of *E. adenophorum* in different light intensity

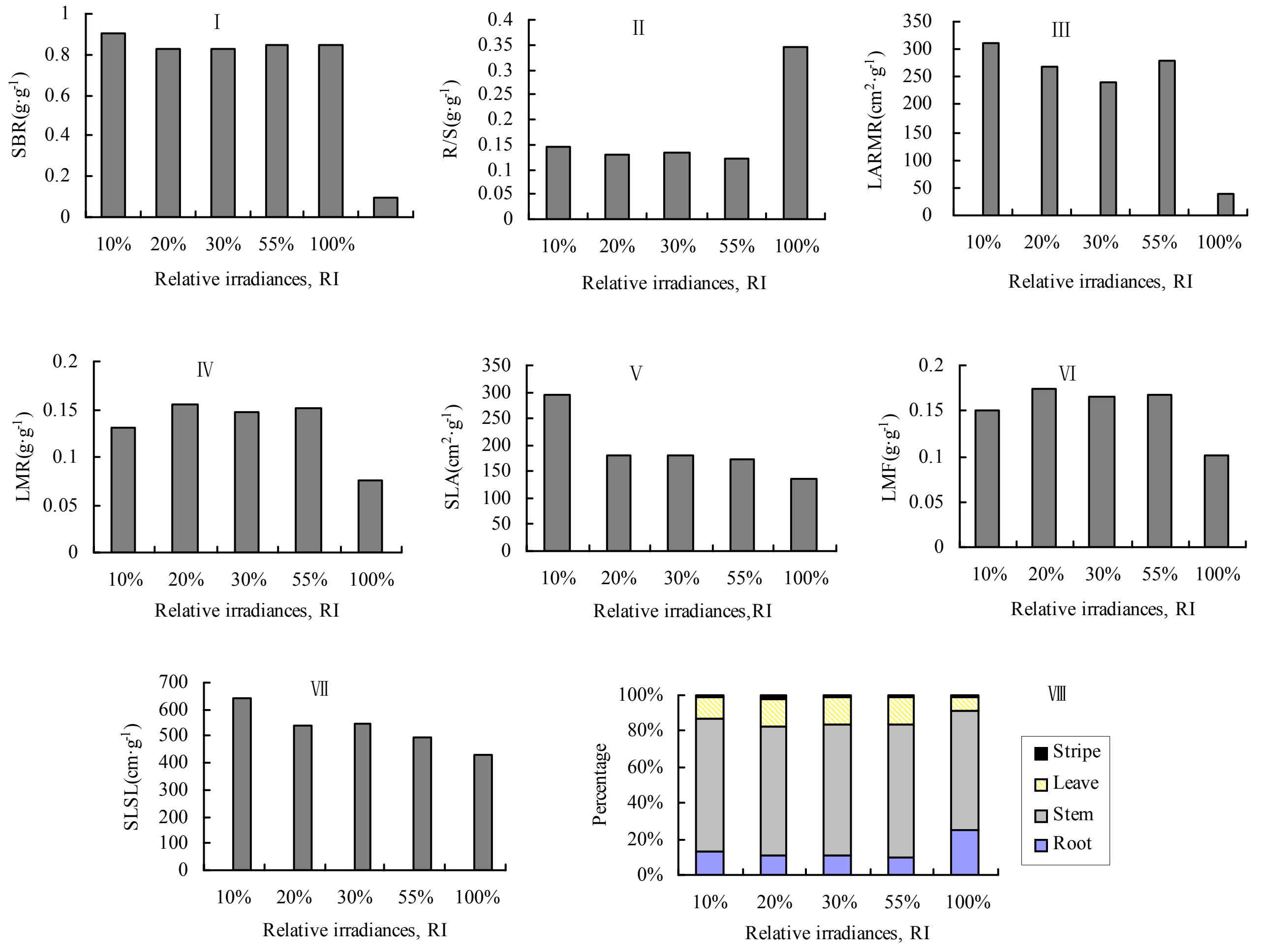

Fig. 2 Biomass allocation characters of *E. adenophorum* under in different light intensity

Leaf is the most important organ for plant accomplishes photosynthesis and accumulates matter. Seen from Fig.2-IV, leaf mass ratio (LMR) in five groups has significant difference ($p<0.05$). We draw a conclusion that specific leaf area increased with the increasing of RI, and the difference is significant ($P<0.01$). Plant may increases leaf area unit biomass to capture more light energy by enlarging and thinning leaf. Leaf mass fraction (LMF) has significance difference ($P<0.05$). Stipe leaf stalk length of different groups have significant difference ($P<0.01$) (Fig2-VII). That indicates plant prolongs its stipe length to capture more light in weak light environment.

The effect of light intensity on the growth of Crofton weed

Mean relative growth rate (RGR) increases within 10%–55% RI and reaches the top at 55% RI, while it decreases in full sunlight (Fig.3-I). Fig 3-II ($P<0.01$) shows that net assimilation rate decreases with RI decrease. It reflects that photosynthesis decreases when in weak sunlight.

Leaf area ration represents the ratio of photosynthesis matter to respiratory matter and it reflects plant pleiophylly. The LAR of plant in different RI has significant difference ($P<0.05$). The difference degree of LAR increases with the decreasing of RI. The rule accords to Kerbs optimum leaf model (Li *et al.* 2000). The data shows that there is no difference for mean leaf area ($p>0.1$) but significant difference for LARm ($p<0.01$) (Fig 3-IV, V).

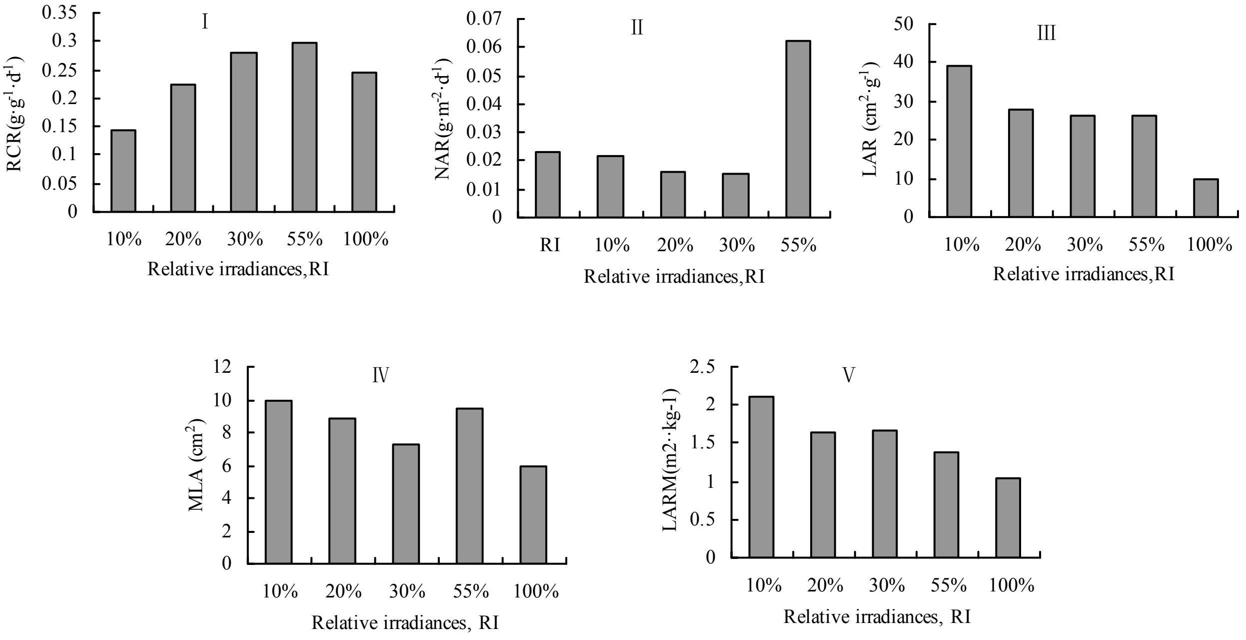

Fig.3 Growth characters of *E. adenophorum* in different RI

Conclusions

Crofton weed can acclimate to different light by its morphological plasticity. Our study shows that the total biomass of Crofton weed increases within the scope of 10%-55% RI but decreases in full sunlight. The height of plant has the same rule. With the increases of RI, stem strips length of plant also increases. In order to acclimate to environment, the plant adjust itself morphological plasticity by prolonging the stem length unit biomass.

In full sunlight, the biomass distribution pattern of Crofton weed seedling is stem > root >leaf >leaf stalk. With decrease of IR, the biomass allocation to leaf is more than to root, at the same time, the biomass allocation to leaf stalk also increases. All the change of biomass allocation to different organs of plant is an ecological strategy for Crofton weed to adapt to the different light intensities. The difference in root mass /crown mass is most significant ($P<0.01$) between the seedling groups treated by full sunlight and shadow. With decrease of light intensity, the biomass allocated to root decreases but biomass allocated to above-ground part relatively increases. From the analysis of specific leaf area, we concluded that plant may increase leaf area unit biomass through thinning and enlarging leaf to capture more light energy.

With RI increases, mean relative growth rate increases ant reach the maximum at 55% RI. In general, net assimilation rate decreases with RI decrease. That indicates that photosynthesis of Crofton weed declines with decrease of light intensity .

Discussions

From above analysis, we found that full sunlight is not the optimum light condition for Crofton weed growth and that slight shadow is be beneficial to Crofton weed growth. The total biomass, height and mean relative growth rate of Crofton weed at 100% RI were lower than those at 30–55% RI.

Under shadow environment, Crofton weed seedling reduces biomass allocation to root but increase biomass allocation to above-ground parts such as leaf, leaf stalk. That may be an ecological strategy of Crofton weed seedling for capturing light in weak light environment. In addition, longer leaf stalk helps leaf reach enough light. Crofton weed increase leaf area unit biomass through thinning and enlarging leaf to capture more light energy, and it displays high ecological adaptation to different light conditions.

In the study, we found that at 100% RI (full sunlight) Crofton weed has obvious daily light inhibition. The total biomass and height of seedlings in full sunlight is lower than that of seedlings in shadow (30–55% RI). Crofton weed shows high shade tolerance. It can still grow at 10% RI. It is reported that Crofton weed seedling can develop monodominant community with only 1.8% transmittancy in canopy, where other plants hardly survive. Therefore, we suggest that self-shade is an effective strategy for Crofton weeds to adapt strong light. The self-shade behavior of Crofton weed can inhibit the growth of other species in its canopy and supplant the other survival plants nearby. The studies from Standish *et al.* (2001) and Niinemets *et al.* (2003) also reported that exotic plant can supplant native plant by shade.

The competition of above-ground parts between plant species depends mainly on the capability of capturing light (Zhang 2002). Our study shows that Crofton weed has a high morphological plasticity to the gradient change of light intensity, indicating that Crofton weed has high adaptation to different light intensity. This might be a main reason that Crofton weed break out all over the word.

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