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Preliminary study on the influence of water level on the growth and morphology of *Limnocharis flava* (L.) Buchenau

V. P. Ranawakage, K. C. Ellawala* and G. G. Tushara Chaminda

Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Hapugala, Galle, Sri Lanka

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Abstract – *Limnocharis flava*, a species native to tropical America, is naturalized as a noxious weed in Sri Lanka, India and some other Southeast Asian countries. It is widespread in flood plains, wetlands and agricultural wetlands resulting in poor drainage. In the current study, the influence of different water conditions on growth, development and morphology of *L. flava* was investigated. Plants were grown on experimental pots filled with wetland soil, simulating flood, standing water and dry conditions. The highest biomass and relative growth rate was observed in the plants grown at flood conditions, while the lowest total biomass content was observed in the plants grown at dry conditions. *L. flava* showed morphological adaptations in different water conditions, including significant differences in the relative biomass allocation for root, petioles and leaves. Root biomass significantly increased in flooded conditions. Observed decrease in leaf area and increase in leaf total chlorophyll content may facilitate the survival in dry conditions. Plant mortality and no production of inflorescence may indicate the difficulty in surviving at dry conditions. No significant difference was observed between the plants grown under 'high flood' conditions and 'low flood' conditions. Overall, *L. flava* showed difficulties to grow under dry conditions, but performed well under other conditions.

Key words: Invasive / plasticity / morphology / *Limnocharis flava* / water conditions

Introduction

Hydrologic conditions are known to be a primary influencing factor on wetland plant communities (Kercher and Zedler, 2004). Successfully colonizing depth for a particular species varies with several factors. Depth and duration of submergence becomes one major factor, others becoming wave action, light availability and characteristics of substrate (Sorrell *et al.*, 2002; Kercher and Zedler, 2004). After colonization, seasonal water-level fluctuations, flooding and drought occurrences may also influence species survival, composition and distribution in wetlands (Deegan *et al.*, 2007; Li *et al.*, 2011). As a consequence of recent urbanization and climate change, frequent flooding and drought conditions are experienced by wetland plant communities. An unfavorable result associated with this phenomenon is the loss of biodiversity in wetlands and the invasion of alien species (Kercher and Zedler, 2004). Invasive species may have traits that show high levels of plasticity, increasing their advantage in survival in different environmental gradients (Gomes and Asaeda, 2009; Zhang and Wen, 2009).

Adaptive plasticity to different and fluctuating environmental conditions may enhance the advantages of survival of invasive species over the others (Kercher and Zedler, 2004; Li *et al.*, 2011). Most common morphological responses to flooding include shoot elongation, variations in biomass partitioning patterns and formation of aerenchyma in shoots and roots (Sultan, 2000; Macek *et al.*, 2006). In addition, variations in parameters such as specific leaf area, relative water content (RWC) and the chlorophyll content in the tissues have been observed by different researchers (Hussner and Meyer, 2009; Li *et al.*, 2011; Richards *et al.*, 2011). Exposure to prolonged dry periods also affects the plant growth, morphology and development (Vasellati *et al.*, 2001). Changing biomass partitioning patterns to increase root–shoot ratio (Asch *et al.*, 2005), changes in the reproduction system (Rodiyati *et al.*, 2005) and extension of roots toward the deeper soil (Dawson, 1993) or laterally (Wan *et al.*, 1996) are some of the strategies encountered in emergent species when exposed to drought.

Limnocharis flava (Alismataceae) is an emergent, anchored, perennial aquatic herb. The species is native to tropical areas of Central and South America. They produce leaves in rosettes, thick angular petioles and

*Corresponding author: ellawala@cee.ruh.ac.lk

umbel-like inflorescences with three to six flowers. The plant mainly propagates by the seeds; one fruit contains thousands of seeds (Brooks *et al.*, 2008). In addition, vegetatively produced juveniles support the propagation (Karthigeyan *et al.*, 2004). It is a noxious weed of wetland areas and agricultural wetlands in Sri Lanka, India, Malaysia, Indonesia and many other Southeast Asian countries (Brooks and Galway, 2006; Abhilash *et al.*, 2008; Brooks *et al.*, 2008). *L. flava* was introduced to Sri Lanka as an ornamental plant in 1898 to 'Peradeniya' botanical gardens (Abhilash *et al.*, 2008). By 1932–1936, it had spread over the country and had almost naturalized as a serious pest in agricultural wetlands (Karthigeyan *et al.*, 2004). Agricultural wetlands are manmade semi-aquatic ecosystems with the purpose of cultivating rice; a wide variety of hydrologic conditions is available in these areas. *L. flava* clogs irrigation tanks and channels, resulting in poor drainage, the abundance sometimes making the area unfit for cultivation. A thorough understanding of the biology and the ecology of the species is necessary in invasive weed management (Abhilash *et al.*, 2008). However, such investigations on *L. flava* growth, survival and reproduction traits under different environmental gradients are limited so far (Brooks *et al.*, 2008). To the best of the author's knowledge, the response of *L. flava* to different water levels available in agricultural wetlands has not been studied in Sri Lanka or anywhere in the world. In addition, most of the studies carried out on the responses of plants to water level have been limited to temperate climates. There are very few studies which have been carried out under tropical climatic conditions. Therefore, the objective of this study was to explore the influence of different water levels on growth, development and morphology of *L. flava* to characterize the probable patterns of spreading of the species in Sri Lanka and other countries in the region.

Materials and Methods

The experiment was conducted in a covered outdoor experimental facility at the Faculty of Engineering, University of Ruhuna, Galle, Sri Lanka (6.08°N, 80.19°E). The temperature was 28 ± 2 °C and the plants were grown in ambient light. The plants and the substrate for plant growth were obtained from a nearby agricultural wetland (TN, 1.69 ± 0.17 mg.g^{-1} dry weight of soil; TP, 0.01 ± 0.004 mg.g^{-1} dry weight of soil). No additional nutrients were added during the experiment. Tap water was used for the study. Twenty-eight young, well-grown and healthy plants (25–30 cm in height) with same morphologies were selected for the experiment. Total fresh weight (FW) of a plant at the beginning was 21.66 ± 8.73 g, which did not significantly vary among plants (ANOVA, $P > 0.05$). None had produced inflorescence at the beginning of the experiment. They were allowed to grow in the experimental pots (one plant in each pot) for 2 weeks prior to the start of experiments. Four pots were used for initial measurements, while the rest were randomly assigned for experimental treatments. One experimental treatment unit consisted of a 60-L plastic container with three plastic nursery pots inside (diameter: 15 cm, height: 17 cm). The experiment was conducted in duplicate. Two setups (six pots) received same water conditions. The positions of the pots and the containers were randomized weekly throughout the experiment.

Experimental conditions

The plants received the following treatments: (1) flooded with 11 cm of water above the soil surface (hereafter called the "high flood" treatment); (2) flooded with 6 cm of water above the soil surface (hereafter called the "low flood" treatment); (3) watered constantly from bottom, in addition added 100 ml of water daily per each pot (no water on top of the soil surface after 30 min of watering) (hereafter called the "standing water" treatment); (4) no water inside the plastic container, added 100 mL of water per each pot once in 3 days. In addition, once in every 21 days, pots were watered from bottom for 3 days to simulate occasional rains (hereafter called the "dry" treatment). Experimental conditions provided under different treatments are depicted in Figure 1. The study was conducted for a period of 72 days.

Harvest and measurement

Plant harvesting was carried out at the end of the experiment period. The plants were gently washed, blotted dry and weighed for total FW. Plant height and root length was measured to the nearest millimeter. Area of each leaf in each plant was recorded manually by placing the leaves on the graph sheets. Then, plants were divided into leaves, petioles, inflorescence and roots. FW of each component was measured separately and allowed to dry in an oven at 70 °C for 72 h. The dry weight (DW) of each part was measured separately.

Relative growth rate (RGR)

Relative growth rate was calculated as,

$$\mathrm{RGR} = Ln\,(\mathrm{DW}_f) - Ln(\mathrm{DW}_i)/t$$

where DW_f is the average dry weight of a plant subjected to any treatment at the end of the experiment period (72 days), DW_i is the average dry weight of a plant at the beginning of the experiment, and t is time in days (Hunt, 1982). Average DW of a plant at the beginning of the experiment was determined by using four plants harvested at the beginning of the experiment.

Specific leaf area (SLA) and RWC

Specific leaf area was calculated as SLA = Leaf area/Leaf DW. Sum of the leaf area of all leaves available in

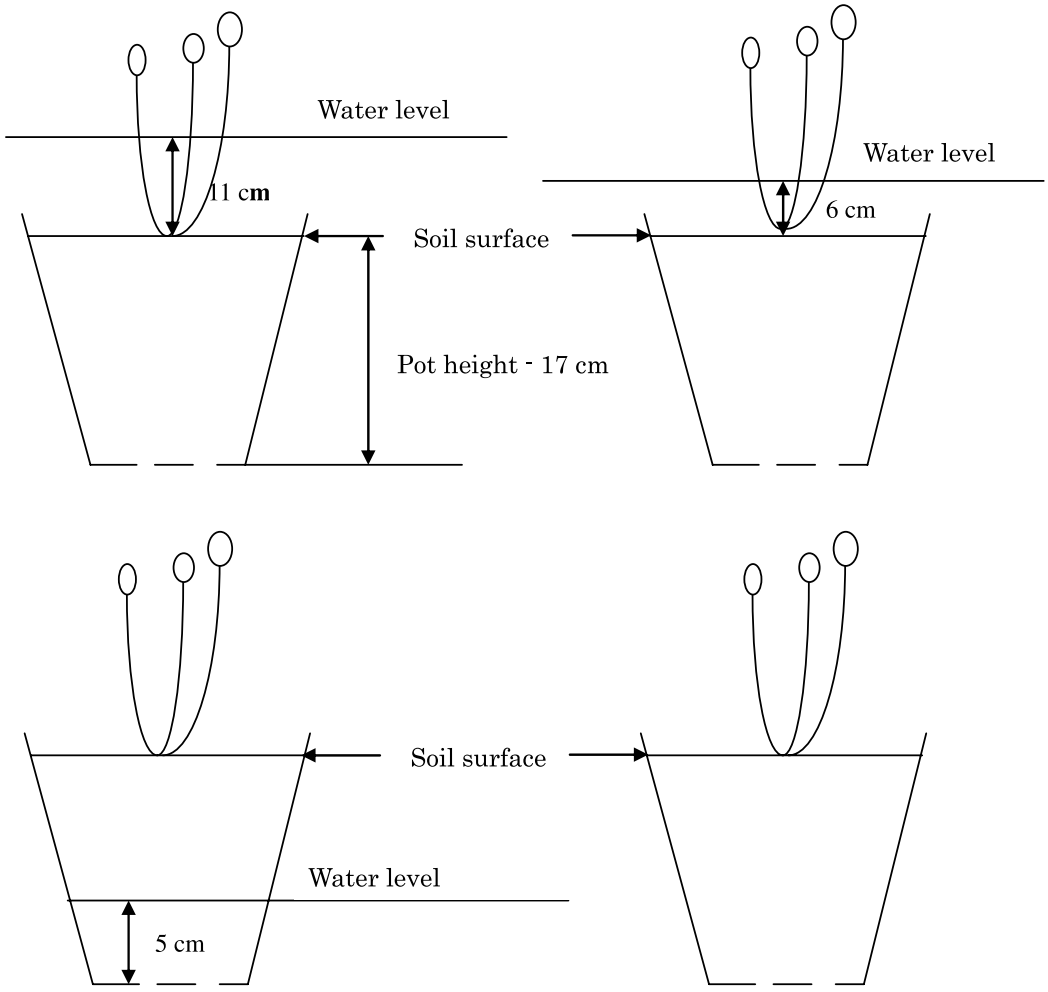

Fig. 1. Experimental conditions employed at each treatment. Water level is measured relative to the soil surface. Nursery pots were placed inside 60 L plastic containers.

one plant was considered as leaf area of the respective plant and the DW of all leaves was considered as leaf DW in the above calculation. Relative water content of the above ground biomass was computed using the formula RWC % = (FW–DW)*100/DW (Hussner and Meyer, 2009).

Total chlorophyll measurements

Leaf total chlorophyll content was determined by extracting chlorophyll in 80% acetone. Total chlorophyll concentration in the extract was measured by using a spectrophotometer (UV 1601 PC, Shimadzu, Japan) and published coefficients were used for calculation (Porra, 2002).

Level of response

The level of response of each parameter to the variation of water level was estimated by the index of response ($Response_{water}$). $Response_{water}$ was calculated as the difference between the maximum and the minimum mean values, divided by the maximum mean value (Quero *et al.*, 2006; Zhang and Wen, 2009). Some authors call this index as the plasticity index (Valladares *et al.*, 2000).

Statistical analysis

All data are presented as mean ± SD. The Kolmogrov–Smirnov test and Levene's check for equality of variances were performed on the data sets prior to the statistical analysis to verify the assumptions of normal distribution and homogeneity of variances. One-way ANOVA was used to check for significant differences among the plants exposed to different water levels at the end of the experimental period. Significant differences among the groups were analyzed with a *post hoc* Tukey test. For all these analyses, the SPSS statistical software package for Windows (Release 13, SPSS INC., Chicago, IL, USA) was used.

Table 1. Plant height, total biomass, specific leaf area, average leaf area, leaf total chlorophyll content, root length, root–shoot ratio, relative water content, number of flowering plants and plant mortality under different water conditions and their $Response_{water}$.

	High flood	Low flood	Standing water	Dry	$Response_{water}$
Plant height (cm)	39.9 ± 1.9^{a}	36.1 ± 2.6^{a}	34.3 ± 2.9^{b}	27.7 ± 8.2^{c}	0.306
Total biomass (g DW)	9.63 ± 3.05^{a}	9.05 ± 2.99^{a}	3.22 ± 0.77^{b}	1.49 ± 0.21^{b}	0.845
Specific leaf area ($cm^2\ g^{-1}$ DW)	300.5 ± 41.7^{a}	289.4 ± 39.8^{a}	374.9 ± 30.4^{b}	328.9 ± 64.1^{b}	0.228
Average leaf area (cm^2)	59.1 ± 11.5^{a}	58.7 ± 17.2^{a}	52.2 ± 9.2^{b}	29.0 ± 4.8^{b}	0.509
Leaf total chlorophyll content ($mg.g^{-1}$ DW)	0.53 ± 0.21^{a}	1.26 ± 0.28^{ab}	1.04 ± 0.35^{b}	1.66 ± 0.25^{c}	0.692
Root length (cm)	36.6 ± 12.5^{a}	29.1 ± 3.3^{ab}	27.1 ± 7.1^{b}	17.3 ± 3.6^{c}	0.527
Root–shoot ratio (% DW)	3.3 ± 1.3^{a}	3.0 ± 0.5^{a}	1.0 ± 0.5^{b}	0.6 ± 0.3^{b}	0.819
Relative water content (% DW) (Based on above-ground biomass)	966.6 ± 106.2^{a}	1025.7 ± 117.1^{a}	998.1 ± 68.5^{a}	869.5 ± 119.4^{b}	0.152
No. of flowering plants	3	2	3	0	-
Mortality (no. of plants)	0	0	0	2	-

The mean $\pm$ SD ($n = 6$) of the data are shown. Means in the same row with different superscript letters are significantly different ($P < 0.05$).

Results

L. flava showed clear adaptations to four experimental conditions. Plants grown at flooded conditions showed a significantly higher total biomass content (ANOVA, $F_{(3, 20)} = 17.060$, $P < 0.001$) (Table 1) compared with plants grown at standing water conditions and dry conditions ($P < 0.002$). Maximum total biomass content, 9.63 ± 3.05 g DW, was observed in high flood conditions and minimum, 1.49 ± 0.21 g DW, was observed in dry conditions. Total biomass content of a plant grown under dry conditions was 84.5% less compared with the average total biomass content of a plant grown under high flood conditions. RWC of the plants grown in dry conditions was relatively lower (ANOVA, $F_{(3, 20)} = 5.163$, $P < 0.01$) compared with plants grown under other conditions ($P < 0.02$) (Table 1). RGR of the plants grown in different water conditions were significantly different (ANOVA, $F_{(3, 20)} = 10.967$, $P < 0.001$), while RGR of the plants grown in dry conditions was 66% less compared to the plants grown in high flood treatment. Plants grown under standing water conditions and flooded conditions had significantly high RGR compared with the plants grown under dry conditions ($P < 0.001$) (Fig. 2). It should be noted that RGR did not significantly vary between the plants grown at two different flooded conditions ($P > 0.05$). $Response_{water}$ in RGR was calculated to be 0.679.

L. flava developed phenotypic plastic adaptations when they are grown under different water conditions. Plant height was significantly less when water availability was less (ANOVA, $F_{(3, 20)} = 13.986$, $P < 0.001$). Plants grown in dry conditions showed significantly low height compared with others ($P < 0.02$). The average height of a plant grown in dry conditions was 30% less compared with the average height of a plant grown in high flood conditions. Plants grown in high flood conditions showed a significant increase in root length (ANOVA, $F_{(3, 20)} = 4.805$, $P < 0.013$) and root biomass compared with plants grown under standing water conditions and dry conditions (ANOVA, $F_{(3, 20)} = 15.296$, $P < 0.001$) (Table 1).

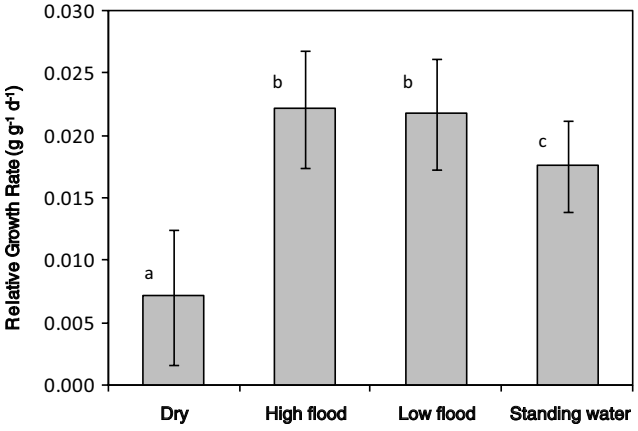

Fig. 2. Relative growth rate of *Limnocharis flava* grown at different water conditions (The mean $\pm$ SD ($n = 6$) of the data are shown, and the vertical bars denote the SD. Letters denote significant differences between means ($P < 0.05$)).

Root–shoot ratio also showed the same pattern as root biomass (ANOVA, $F_{(3, 20)} = 13.428$, $P < 0.001$). Dry conditions reduced the root–shoot ratio by 85% and the maximum value was observed in the plants exposed to high flood conditions (Table 1). Relative biomass amount of leaves (ANOVA, $F_{(3, 20)} = 49.504$, $P < 0.001$) and petioles (ANOVA, $F_{(3, 20)} = 16.296$, $P < 0.001$) were significantly lower while the relative biomass amount of roots was significantly higher (ANOVA, $F_{(3, 20)} = 24.270$, $P < 0.001$) at flooded conditions compared with the dry and standing water conditions ($P < 0.001$) (Fig. 3).

Plant leaf area significantly decreased with water availability (ANOVA, $F_{(3, 20)} = 4.646$, $P < 0.015$). Further, SLA also showed significant differences among the plants grown at different water conditions (ANOVA, $F_{(3, 20)} = 5.012$, $P < 0.01$) (Table 1). Initially average leaf area of a plant was 52.9 ± 14.0 cm^2. Newly emerged leaves showed a reduction in the leaf area when they were grown at dry conditions, hence there was a reduction in the average leaf area at the end of the experiment period compared to beginning of the experiment. Reduction of

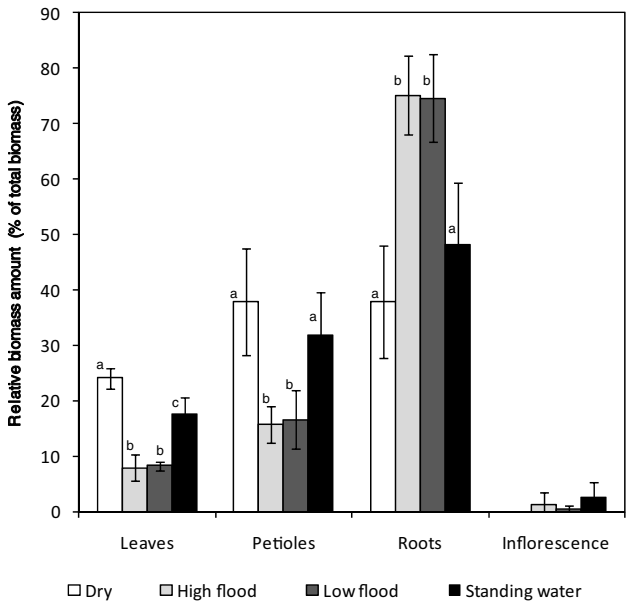

Fig. 3. Relative biomass allocation of *Limnocharis flava* at different water conditions, at the end of the experiment period (The mean ± SD ($n = 6$) of the data are shown, and the vertical bars denote the SD. Letters denote significant differences between means ($P < 0.05$)).

the average area of a leaf was 51% when the plants were exposed to dry conditions, compared with the plants exposed to high flood conditions. However, highest leaf total chlorophyll content was observed in the plants grown in dry conditions (ANOVA, $F_{(3, 20)} = 5.266$, $P < 0.027$) ($P < 0.05$), while the lowest was observed in the plants grown under high flood conditions ($P < 0.03$).

$\text{Response}_{\text{water}}$ in plant height, SLA and RWC was less than 0.5, while it was higher than 0.5 for all the other parameters measured, indicating that *L. flava* shows plastic responses in many parameters. Plants grown in dry conditions showed no production of inflorescence, while the plants grown in other conditions showed inflorescence production. Moreover, plant mortality was observed under dry conditions only. All the plants survived under other treatment conditions.

Discussion

L. flava is an aquatic plant alien to Sri Lanka and other countries in the region. *L. flava* invasion in agricultural wetlands exists as a mono-species colonization which covers the whole area with time, outcompeting other species available in the area. Usually, invasive alien species are more tolerant to environmental stresses than the native species (Burns, 2004; Zhang and Wen, 2009) and show greater phenotypic plasticity compared with the native species (Davidson *et al.*, 2011). *L. flava* rapidly spreads in wetlands and agricultural wetlands. This study is aimed to characterize the probable spreading patterns of this species in Sri Lanka, India and other Southeast Asian countries having same climatic conditions. Therefore, the experimental conditions for this study were selected for simulating four water levels usually available in wetlands and agricultural wetlands in Sri Lanka, in which the invasion of *L. flava* is a serious threat on their functioning. "High flood" and "low flood" conditions chosen for the study are common in Sri Lankan agricultural wetlands in monsoon rain periods, while "standing water" condition is available in inter-monsoon rain periods. "Dry" conditions were selected for simulating prolonged drought periods with occasional rains.

In this study, *L. flava* responded to the reduced water availability by producing less biomass, which is a common phenomenon observed in other wetland species also (Hussner and Meyer, 2009). Increase in relative biomass allocation for root and root–shoot ratio at flooded conditions indicates that they are employing the escaping strategy at submersion (Sultan, 2000). Adventitious root development helps them to escape root zone anoxic conditions at submersion, which is a common strategy observed in wetlands plant species (Kercher and Zedler, 2004; Jackson *et al.*, 2009). Upward growing roots, same as those observed in *Ludwigia* (Ellmore, 1981), were observed in *L. flava* in our study. According to Ellmore (1981), such adventitious roots in aquatic plants are derived from primary cortex rather than a secondary meristem. Furthermore, Ellmore (1981) suggests that this may reflect a general difference between plants that normally grow in aquatic environments and flood-tolerant species.

Relative biomass allocation for leaves and petioles was higher at low water conditions. In contrast, leaf area was less at low water conditions. Reduction in leaf area may be an effective adaptation mechanism to low water availability since it reduces the water loss by transpiration (Li *et al.*, 2011). In addition, higher chlorophyll density in dry conditions may encourage survival by increasing the rate of photosynthesis, though the leaf area is less. Variations were observed in relative biomass allocation, reproduction traits and RWC among different water levels. Wetland plants show this type of adaptations when they are exposed to different water conditions (Kercher and Zedler, 2004; Hussner and Meyer, 2009; Li *et al.*, 2011).

The results of this study indicate that *L. flava* is able to grow at flooded and standing water conditions, successfully changing their phenotype; however, they find difficulties in survival when exposed to dry conditions. Plants produced inflorescence at all experimental conditions other than dry conditions. Low RGR, plant mortality and no reproduction under dry conditions may be considered as the signs of difficulty in survival under dry conditions. It should be noted that there were no significant differences observed between the plants grown under high and low flood conditions. Therefore, it can be hypothesized that *L. flava* may not be sensitive to the water level but is sensitive to the water availability. They successfully grow on flooded and saturated soils, though they are not competent in growing under dry

weather conditions. The response of native species to the above-mentioned water levels has never been studied under Sri Lankan conditions. A comparison of the plastic behavior of *L. flava* with one of the native species may explain more about the invasive characteristics of *L. flava*, hence further research in this area is recommended.

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