ECOLOGICAL CHARACTERISTICS OF THREE INVASIVE PLANTS (*LEUCAENA LEUCOCEPHALA*, *MIKANIA MICRANtha*, AND *STACHYTARPHEta URTICAxEFOLiA*) IN SOUTHERN TAIWAN

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ABSTRACT

This Bulletin discusses the ecological characteristics of three invasive plant species in Taiwan, *Leucaena leucocephala*, *Stachytarpheta urticaefolia* and *Mikania micrantha*, in order to understand their life cycles and invasive mechanisms. It also describes some practices, mainly manual techniques, that are currently being used to control the spread of *L. leucocephala* and *M. micrantha*. The potential of using allelopathic methods against the three invasive species is discussed.

INTRODUCTION

At low elevations in southern Taiwan, the weather is hot and tropical. As a result of changes in land-use patterns, many invasive species such as *Leucaena leucocephala* and *Stachytarpheta urticaefolia* have occupied abandoned fields and become pure stands. In the past five years, an exotic climber, *Mikania micrantha*, has also expanded rapidly. All three species are a serious threat to both native plant communities and agricultural areas.

*Leucaena*

*Leucaena* (*Leucaena leucocephala* (Lam.) de Wit), is a small leguminous tree, originally from Central America. It can survive in dry areas with poor soils because of its nitrogen fixation ability (Cronk and Fuller 1995). It was introduced into Taiwan, probably by the Portuguese or the Dutch, in the seventeenth century. In the past, when Taiwan’s economy was not as prosperous as today, farmers used leucaena leaves to feed their livestock, and the twigs as fuel. In this way, populations of *L. leucocephala* were kept in check.

In the 1980s, patterns of land use changed. Many pastures and fields were abandoned and became overgrown. In addition, people in Taiwan no longer depended on wood for fuel because they had electricity. Thus, there was no need to harvest leucaena trees. As a result, populations of leucaena increased rapidly in the 1980s. They formed pure stands in large areas, especially in the Hengchun Peninsula of southern Taiwan and the islands of Penghu. We do not yet have detailed information as to the total area occupied by leucaena so far, but several institutes are planning to study the distribution by remote-sensing techniques.

*L. leucocephala* invades a forest with a partially open canopy, for example, the tropical coastal forests at the extreme south of Taiwan. It can also easily become an established population in abandoned farms, and will become a pure stand in five years. If a leucaena tree is cut down, about twenty sprouts grow from the cut trunk. The sprouts can grow 30 cm in one month, 80 cm in two months, and to the original height of the tree in a few years. The density of the regrowth will be even higher than that of the original
trees before cutting. Furthermore, *L. leucocephala* produces a large number of seeds every year. These seeds can remain viable in the soil for many years. Small seedlings may germinate from the soil seed bank several years after the removal of *L. leucocephala* trees. Therefore, it is a difficult task to rehabilitate an ecosystem which has been invaded by *L. leucocephala*. Adding to the difficulty is the strong allelopathic potential of *L. leucocephala* (Chou and Kuo 1986). The leaves of the tree produce toxic chemicals which inhibit the germination and growth of other trees. This increases the competing capability of *L. leucocephala* even more. We need to learn more about the ecological characteristics of *L. leucocephala*, in order to find the most efficient method of preventing its future invasion, and of rehabilitating ecosystems which it has already colonized.

**Mikania micrantha**

Another important invasive weed in Taiwan is one of the Compositae, *Mikania micrantha* H.B.K., a perennial climber. It is sometimes known as "mile-a-minute" or "bittervine". It is quite similar in appearance to *M. cordata*, a species native to Taiwan. Originating in tropical Central America, *M. micrantha* caused severe economical losses in Asia in the 1920s, for example in India (Palit 1981). In the 1980s, it invaded the provinces of southeastern China and created serious ecological problems (Huang et al. 2000, Kong et al. 2000a,b). It was also introduced into Taiwan in the 1990s, and quickly spread in tropical areas with an elevation of less than 1000 m.

The vines climb up to the top of the canopy of trees and create dense cover. Fallow fields may also be fully covered by *M. micrantha*. This invasive plant has caused severe damage to newly established plantations and orchards. Furthermore, when the vines of *M. micrantha* cover the tree crown, they affect not only the photosynthesis of the tree, but also the habitat of birds. Since 2000, the government and civil conservation organizations have actively worked to prevent the spread of *M. micrantha*. This Bulletin describes the ecological characteristics, including the phenology, shade tolerance and reproduction, of *M. micrantha*. It also evaluates the possibilities of applying allelopathic methods and mechanical means to control the spread of *M. micrantha*.

**Stachytarpheta urticaefolia**

The third invasive weed is porterweed, (*Stachytarpheta urticaefolia* (Salisb.) Sims). A species of Verbenaceae, it is a woody herb with a height of around 80-120 cm. Originally from tropical America, it was introduced to Taiwan in the 1900s, possibly as an ornamental plant (Chen and Hu 1976). *S. urticaefolia* is also strongly invasive. Since its appearance on the Hengchun Peninsula in the 1960s, it has quickly spread, either forming pure stands or mixed with another exotic invasive species, *Lantana camara* (Hu 1961, Wang 1976).

From the 1950s to the 1970s, many virgin forests on the Hengchun Peninsula were logged and replanted with *Agave sisalana*. *A. sisalana* was used as a raw material (sisal hemp) for making rope, and was of high economic value during that time (Billings 1988). However, prices for *A. sisalana* fell in the 1980s, and many plantations were abandoned. They became a habitat for *S. urticaefolia* and *L. leucocephala*. At present, we can find *S. urticaefolia* occupying large stretches of roadsides and abandoned land on the Hengchun Peninsula, even in the Ecological Reserves of the Kenting National Park. It seriously threatens the survival of native herbaceous and shrub communities. The ecological characteristics and allelopathic potential of this species were studied, in order to clarify its invasive mechanisms.

The experimental methods followed are shown in Appendix 1.

**CONTROL OF LEUCAENA LEUCOCEPHALA**

Leucaena (*Leucaena leucocephala*) was found in 9,020 ha of forested lands investigated in Kenting, a national park in southern Taiwan (Lu 2002), as well as in many areas outside the park. Of the land occupied by leucaena, there were 1,405 ha where the density of the leucaena trees was higher than 75%, and 1,974 ha where their density was between 50% and 75% (Lu 2002). Leucaena trees are only 2-3 m high in sites exposed to the prevailing wind, or on the steep slopeland of the Hengchun Peninsula.
Trees may reach 6-7 m in height if they are shielded from the wind or growing in favorable soils. The height of leucaena trees in the sampling plots we investigated was about 6 m. A high plant density was 18,850 stems/ha, with an average of 1.9 stem/m². The class of DBH (diameter at breast height) of 4-6 cm, included about 31% of all the trees. Only 6.2% of the trees had a DBH greater than 10 cm.

**The soil seed bank**

In order to know how many leucaena seedlings could germinate from the soil seed bank after the removal of the trees, we monitored the number of newly germinated seedlings of *L. leucocephala* once a fortnight over a period of 20 weeks after removing the trees. All seedlings were pulled out after each count. At the second and the fourth week, about 20,000 seedlings per hectare were counted (Fig. 1). At the sixth week, there were as many as 32,000 seedlings per hectare. However, the number of newly germinated seedlings declined at the eighth, tenth, and twelfth weeks (Fig. 1).

It is clear that the number of seedlings germinating reached a peak in the sixth week, and then gradually declined. However, in late November, pods from leucaena trees growing near the edge of the site started to spread into the sampling plots. Consequently, a large number of young seedlings germinated in the 14th week, reaching 35,000 seedlings per hectare (Fig. 1). By the 18th week, there were as many as 48,000 seedlings per hectare. In this experiment, we removed the chopped-down leucaena trees from the site soon after they were felled, before the seeds started to germinate.

Seedlings germinating during the first 12 weeks were supposed to have germinated from the soil seed bank. However, seedlings found after 14 weeks may have germinated from the newly shed seeds, i.e. the seed rain. In a situation where there is rain and cleared soil with no coverage, as in the case of our study site, an enormous number of leucaena seeds can germinate in a short time. This is one of the reasons why leucaena can quickly invade disturbed open areas.

The high seed productivity of leucaena makes it difficult to control its invasion. Control of persistently generating seedlings, and preventing the trunks of felled trees from producing sprouts, are two of the most important aspects of controlling invasive leucaena. Currently, the measure we take to control sprouts is to apply Glyforside, a conductive herbicide, to the surface of the trunk immediately after the tree has been cut down. This operation has to be finished no later than March, one month before the end of the dry season. It reduces the number of sprouts, and delays sprouting for at least one month.

For the problems with the soil seed bank, the measure we employ is that we first let seeds in the soil germinate freely. Then, after eight weeks, we remove all the seedlings. At this time, it is late May or early June when the rainy season begins. The cleared forest floor is densely planted with seedlings of fast-growing native trees, such as *Acacia confuse*, *Macaranga tanayius*, *Trema orientalis* and *Bischofia javanica*, so that the ground is quickly covered with vegetation. The large number of native species alters the light environment, so that the leucaena seeds can no longer germinate in large numbers.

Another measure is to spread seeds of native tree species on the forest floor after the removal of leucaena trees. No manual planting is used. We allow the seedlings of fast-growing native trees to compete with leucaena seedlings. This procedure can of course be accompanied by the manual removal of leucaena seedlings. We have begun using all these measures, and will evaluate the results at the end of the year (2003).

**CONTROL OF MIKANIA MICRANTHA**

Bittervine (*Mikania micrantha*) is a climbing plant which is intolerant of shade. Seedlings of this species cannot survive in a forest understory with 2% relative light intensity. Seedling biomass was significantly higher when seedlings were grown in a 35% light environment, compared to a 10% light environment (Table 1). Studies on the relationship between the weather and plant growth showed that peak flowering of *M. micrantha* occurred in November and December (this is winter in Taiwan), with prolific seed production of 0.17 million seeds per square meter of ground. During the winter season most of the leaves will be shed. New leaves will sprout in the spring, indicating that the...
vine is a perennial.

To prevent *M. micrantha* from spreading, we developed an effective procedure based on cutting the vines close to the ground once a month for three consecutive months (see Appendix 1). If the vines were cut only once in summer or autumn, 50% of the cut vines resprouted (Table 2). Cutting the vines twice resulted in 90% mortality of the vines. Three consecutive cuttings eliminated 92-98% of the vines.

However, this method was less effective during winter and spring. More than 70% of the cut vines re-sprouted if they were cut only once in winter or spring (Table 2).

In practice, spraying chemicals may be the easiest way to control *M. micrantha*. In fact, many farmers in Taiwan prefer to use herbicides to control this vine in open fields. However, the possibility of environmental contamination and public health risks if chemicals are used to control the widespread weed *M. micrantha* is of great concern. From considerations of environmental safety and practical effectiveness, the Forest Bureau of Taiwan has been using the consecutive-cutting method since 2001 to control *M. micrantha*. The vines are cut manually for the first time 20 cm above the ground in late August (i.e. late summer in Taiwan). Three weeks later they are cut for a second time, to remove all the new sprouts. After another three weeks, the area is checked and all the remaining *M. micrantha* sprouts are cut. In 2001, this invasive vine was controlled on more than 900 ha of forest. The results were promising. However, this control operation was expensive, costing about US$480 thousand in 2001. The Forest Bureau of Taiwan plans to apply this method of control to another 16,000 ha of forest in 2003.

We also evaluated the allelopathic potential of 19 plants against *M. micrantha* seedlings. We found that the leaves and flowers of flame tree (*Delonix regia*) showed strong phytotoxicity against *M. micrantha*. A mulch of 1-2 g of powdered leaves or flowers on the soil surface caused 75-90% mortality within 3 weeks in *M. micrantha* seedlings grown in pots (Table 3). Spraying a 4% aqueous extract of leaves of *D. regia* on leaves of *M. micrantha* seedlings also resulted in some mortality (data not shown). These results show that it may be possible to use allelochemicals present in the leaves and flowers of *D. regia* as a natural herbicide to control *M. micrantha*.
Porterweed (S. urticaefolia) plants bear around 35 spikes each. These flower for most of the year under favorable conditions. The length of the spikes ranges from 25 cm to 50 cm. Every centimeter of the spike contains four capsules, and each capsule has two seeds. Therefore, a single plant may produce over 7,000 seeds in one growing season.

The seeds can germinate under dark conditions, but when illuminated, the germination rate increased to more than 70%. In addition to prolific seed production, porterweed plants may reproduce vegetatively. If the stalks are forced flat against the ground, many adventitious roots and new sprouts may develop from the nodes of the stems.

In our shading experiments, we found S. urticaefolia to be a shade-intolerant species. Biomass production was significantly higher under high levels of light (Table 3). Under low light levels, the number of spikes was significantly reduced (Fig. 3 and Fig. 4), and the spikes took longer to develop (Fig. 5). Field measurements of photosynthetic response to light showed that this species had a very high rate of net photosynthesis in the open field, higher than 26 µmol CO₂ m⁻²/s. This indicates that S. urticaefolia has a high primary production capacity. This species also showed a remarkably high rate of photosynthesis under low light conditions. For example, its net photosynthetic rates at a light intensity of 50 and 100 µmol photon m⁻²/s were 2.28 and 5.56 µmol CO₂ m⁻²/s, respectively, which were about twice as high as those of shade-intolerant trees.

S. urticaefolia also has strong allelopathic potential. Aqueous leaf extracts of this species inhibited the seed germination and radical growth of many local herbaceous plants, including Spanish needles (Bidens bipinnata) and Senna (Cassia tora) (Fig. 6). Allelopathic activity was also observed in pot experiments using decaying leaves of S. urticaefolia. Mulching the pot surface with the powdered leaves of S. urticaefolia caused high mortality in Cassia tora, Bidens bipinna, Giant Sensitiveplant (Mimosa invisa), and Willow leaf (Hygrophila salicifolia) (Fig. 7). The biomass of the surviving seedlings was significantly reduced in four out of the six species tested, including leucaena (Fig. 7). The allelopathic relationships among Formosa acacia (Acacia confusa), Vitex negundo, L. leucocephala, and S. urticaefolia, all of which inhabit the same drought-prone sites of the Hengchun Peninsula, were also evaluated. The results showed that both A. confusa and L. leucocephala promoted, while V. negundo inhibited, the growth of S. urticaefolia seedlings (Fig. 7).
Table 1. Effects of different light regimes on biomass allocations of *Mikania micrantha* seedlings after three months of treatment, mean ± SD (n = 8)\(^1\)

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Understory (2%)</th>
<th>10%</th>
<th>35%</th>
<th>65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves (g)</td>
<td>-</td>
<td>1.14 ± 0.58(^b)</td>
<td>1.66 ± 0.95(^a)</td>
<td>1.11 ± 0.37(^ab)</td>
</tr>
<tr>
<td>Stems (g)</td>
<td>-</td>
<td>1.19 ± 0.39(^b)</td>
<td>1.73 ± 0.91(^a)</td>
<td>1.23 ± 0.39(^ab)</td>
</tr>
<tr>
<td>Roots (g)</td>
<td>-</td>
<td>1.16 ± 0.07(^c)</td>
<td>0.49 ± 0.19(^b)</td>
<td>1.03 ± 0.40(^c)</td>
</tr>
<tr>
<td>Total weight (g)</td>
<td>-</td>
<td>2.54 ± 1.10(^b)</td>
<td>3.54 ± 1.17(^a)</td>
<td>3.28 ± 0.66(^ab)</td>
</tr>
</tbody>
</table>

\(^1\) Values in a row with the same letter do not significantly differ at the 5% significance level by Scheffe's multiple-comparison procedure.

\(^2\) All seedlings died after two months of treatment in the forest understory.

Table 2. Cumulative mortality of *Mikania micrantha* vines after being cut at different seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Date of first cutting</th>
<th>1st cutting</th>
<th>2nd cutting</th>
<th>3rd cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>June 22, 2000</td>
<td>50</td>
<td>88</td>
<td>98</td>
</tr>
<tr>
<td>Autumn</td>
<td>Sept. 28, 2000</td>
<td>50</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Winter</td>
<td>Dec. 30, 2000</td>
<td>30</td>
<td>44</td>
<td>60</td>
</tr>
<tr>
<td>Spring</td>
<td>March 29, 2001</td>
<td>4</td>
<td>24</td>
<td>52</td>
</tr>
</tbody>
</table>

Fig. 3. Number of spikes of *Stachytarpheta urticaefolia* grown under four light regimes, after various lengths of time since shade treatment. Bars with the same letter(s) in each set do not significantly differ at the 5% significance level.
strong allelopathic potential against *L. leucocephala*. These findings may show the potential use of naturally occurring allelochemicals to control unwanted invasive plants in the future.

The following ecological characteristics of *S. urticaefolia* may be suggested as the reasons for its success as an aggressively invasive species:

- Prolific seed production and easy dispersal of seeds by wind;
- Ability to regenerate vegetatively;
- Production of allelopathic and repellent substances; and
- A high primary production rate.

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Table 3. Inhibitory effect of mulching seedlings of *Mikania micrantha* with powdered leaves or flowers of *Delonix rigid*

<table>
<thead>
<tr>
<th>Mulching material</th>
<th>Weekly cumulative total of dead plants</th>
<th>Mortality (%)</th>
<th>Biomass (mg/plant)</th>
<th>Biomass inhibition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powdered leaf</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 g (n = 40)</td>
<td>16 26 29 30 30 75</td>
<td>174 ± 28</td>
<td>-48</td>
<td></td>
</tr>
<tr>
<td>2 g (n = 20)</td>
<td>8 14 15 16 16 80</td>
<td>215 ± 30</td>
<td>-35</td>
<td></td>
</tr>
<tr>
<td>Powdered flower</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 g (n = 40)</td>
<td>30 35 36 36 36 90</td>
<td>99 ± 21</td>
<td>-70</td>
<td></td>
</tr>
<tr>
<td>2 g (n = 20)</td>
<td>14 17 17 18 18 90</td>
<td>148 ± 4</td>
<td>-55</td>
<td></td>
</tr>
<tr>
<td>Control (n = 20)</td>
<td>0 0 0 0 0 0</td>
<td>330 ± 27</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

1) Negative values denote inhibition.

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Fig. 4. Number of spikes at various flowering stages of *Stachytarpheta urticaefolia* grown under four light regimes at the end of shade experiments. Bars with the same letter in each flowering stage do not significantly differ at the 5% significance level.
Fig. 5. Percent inhibition of radicle growth of four local herbaceous plants caused by 0.5% and 1.0% leaf extracts of *Stachyartheta urticaefolia*. Asterisks denote significant difference from the controls ($p \leq 0.05$).

Fig. 6. Mortality and percent biomass inhibition of six test species affected by a mulch of powdered leaves of *Stachyartheta urticaefolia*. An asterisk denotes a significant difference from the control ($p \leq 0.05$).
Fig. 7. Allelopathic relationships among Acacia confusa, Leucaena leucocephala, Stachytarpheta urticaefolia, and Vitex negundo

+: stimulation; -: inhibition; 0: neutral

REFERENCES


APPENDIX 1: METHODS OF STUDYING
THE INVASIVE WEEDS

**Leucaena leucocephala**

In order to monitor potential recruits of *L. leucocephala* germinating from the soil seed bank after the removal of *L. leucocephala* trees, four sampling plots of 10 m x 10 m were chosen in a stand near Kenting, in southern Taiwan. The stand was a pure *L. leucocephala* stand with trees about 6 m high. After recording the diameter of the trunks at breast height, all *L. leucocephala* trees were cut at 5 cm above the ground and removed on September 4th, 2002. Twice a week for the next 20 weeks, a survey was made of the number of new seedlings. Seedlings were removed manually after they were counted.

**Mikania micrantha**

*Shade experiments*

*M. micrantha* sprouts were grown in shadehouses with 65%, 35%, and 10% of full sunlight, and also as understory in a natural forest. After three months of treatment, sprouts were harvested and their dry weight was measured.

**Consecutive-cutting experiment**

In order to evaluate the effect of the timing and the thoroughness of mechanical cutting, we performed cutting experiments in spring, summer, autumn and winter. Fifty vines of mature *M. micrantha* were used in each experiment. The vines were marked, and cut at a point 15-20 cm above the ground. One month later, the number of vines with new sprouts were counted. These were then cut a second time. After another month, the number of vines still alive was counted, and they were cut a third time. Three months after the first cutting, we recorded the number of vines still sprouting. This consecutive-cutting experiment was repeated four times, from summer 2001 to spring 2002, in such a way that the first cutting was always at the beginning of the season, and each season was eventually included.

**Allelopathic experiment**

We used powdered leaves of 19 plant species to test the potential phytotoxicity against *M. micrantha* seedlings (Kuo et al. 2002). The results showed that of these 19 species, only one, *Delonix regia*, could cause high mortality in *M. micrantha*. We then conducted another allelopathic experiment, using 1-2 g of *D. regia* powdered leaves or flowers as a mulch to confirm the toxic effect on *M. micrantha*. The mortality of *M. micrantha* seedlings was recorded weekly for five weeks. The dry weight of surviving seedlings was also measured.

**Stachytarpheta urticaefolia**

*Germination rate of seeds*

The germination rate of seeds was tested under illuminated or dark conditions. Thirty seeds were placed in a Petri dish with four replicate dishes per treatment in a growth chamber of 30/27°C (day/night). Seeds under illuminated conditions received 25-30 µmol photon m⁻²/s 24 hours per day. For the dark treatment, Petri dishes were covered with two layers of aluminum foil. The number of germinated seeds was recorded, and germinated seeds were removed, every day for 17 days.
**Shade experiment**

Two-months-old seedlings of *S. urticaefolia* were placed in 100%, 75%, 40%, and 20% of full sunlight for six months. The abundance of spikes, and the number of spikes at various flowering stages per plant under four light regimes, were recorded.

**Photosynthetic light response**

Five *S. urticaefolia* plants growing in an open field were monitored for their photosynthetic light response in November 2000. Photosynthetic rates under various levels of light intensity, from 0 to 2200 µmol photon m⁻²/s, were measured with a portable photosynthetic system (LI-6400, LI-COR, USA). Leaf temperatures were controlled at 28°C, and CO₂ concentrations were 360 µl/l for all measurements.

**Bioassay**

Sponge bioassay techniques (Kuo et al. 1989) were employed in this study. Fresh leaves of *S. urticaefolia* were air-dried and ground into power. Next, 0.5% and 1.0% aqueous extracts were made for bioassay. Seeds of Chinese cabbage (*Brassica chinensis*), lettuce (*Lactuca sativa*), as well as two local herbaceous plants, *Cassia tora* and *Bidens bipinnata*, were used as the test materials.

Thirty seeds of each species were placed in a Petri dish, with three replicate dishes per test extract. The Petri dishes were incubated at 25°C for three days. The percentage of germination seeds and the length of the radicle (embryonic root) were then recorded.

**Pot experiment**

Newly germinated seeds of *Achylanthus obtusifolia*, *Bidens bipinnata*, *Cassia tora*, *Hygrophila salicifolia*, *Mimosa invisa*, and *Leucaena leucocephala* were planted in plastic pots 7.6 cm in diameter and 7 cm in depth. Four grams of the powdered leaves of *S. urticaefolia* were placed on the soil surface of the pots and allowed to decompose. There were 15 replicates for each species. Pots covered with the same amount of vermiculate served as the controls. After 55 days of growth, the dry weight of the surviving seedlings was measured.