Weed Technology 2010 24:574–582

Distribution, Growth, and Seed Germination Ability of Lead Tree (*Leucaena leucocephala*) Plants in Penghu Islands, Taiwan

Chen-Yu Hwang, Ling-Ming Hsu, Yow-Jang Liou, and Ching-Yuh Wang*

The distribution, growth, and seed germination ability of the exotic lead tree in Penghu Islands, Taiwan, were studied. Survey results have shown that all lead tree plants existing throughout these islands belonged to the Hawaii type. Subsequently a comparison of germination requirements between this and the rare Salvador type, which distributes only in the island of Taiwan, was carried out. The objective of this research was to compare the germination requirements of the Salvador- and Hawaii-type lead tree plants. Lead trees in Penghu Islands have formed a pure forest with a height ranging from 2 to 4 m. All growth stages of the lead tree, i.e., vegetative, flowering, podding, and depodding stages, were found simultaneously in fall, but only vegetative and podding stages were observed in summer. Germination of both the Hawaii- and Salvador-type lead tree was evaluated under different environmental conditions, including temperature, pH, osmotic potential, burial depth, and lighting condition.The Salvador-type exhibited more than 60% seed germination after 14 d at temperatures between 20 and 35 C, whereas the seed germination of the Hawaii type increased from 20 to 60% with temperature increases from 20 to 35 C. The optimal temperature for seed germination of these two types of lead tree was 35 C. Increasing burial depth beneath the soil surface and darkness, as well as an osmotic potential below −0.4 MPa, also reduced seed germination. However, the germination of both types was not affected by pH ranging from 4.0 to 9.0. On the basis of the climatic and soil environment conditions in Penghu Islands, it is reasonable to predict that the summer season, in which lead tree seeds readily germinate on the ground or in shallow soils, is the optimal time for controlling this plant.
Nomenclature: Lead tree, *Leucaena leucocephala* (Lam.) de. Wit.
Key words: Geographic, climatic, environment, invasive weed, native species, time to control.

La distribución, el crecimiento y la habilidad de germinación de la *Leucaena leucocephala* (Lam.) de. Wit., se estudiaron en las Islas Penghu, Taiwán. Los resultados de la muestra revelaron que todas las plantas de *Leucaena leucocephala* (Lam.) existentes en estas islas pertenecen al tipo Hawaii. Subsecuentemente se realizó una comparación de los requisitos de germinación entre este árbol y el de la tipo denominado Salvador, especie rara que se encuentra solamente en la Isla de Taiwán. El objetivo de esta investigación fue comparar los requisitos de germinación de las plantas *Leucaena leucocephala* (Lam.) de los tipos Salvador y Hawaii. Las plantas de esta especie en las Islas Penghu han formado un bosque uniforme con una altura que varía de 2 a 4 m. Todas las etapas de crecimiento de la *Leucaena*, ejemplos: vegetativa, florecimiento, formación y apertura de las vainas, se observaron simultáneamente en el otoño, pero sólo el estado vegetativo y el de formación de la vaina se observaron en el verano. La germinación de ambos tipos de plantas, se evaluó bajo diferentes condiciones ambientales, incluyendo temperatura, pH, potencial osmótico, profundidad de siembra y condiciones de luz. El tipo Salvador mostró más del 60% de germinación de semillas después de 14 días, a cualquier temperatura entre 20 y 35 C, mientras que la del tipo Hawaii se incrementó de un 20 a un 60% en respuesta los aumentos en la temperatura a partir de los 20 hasta los 35 C. La temperatura óptima para la germinación de las semillas de estos dos tipos de *Leucaena leucocephala* (Lam.) fue de 35 C. También se observó una disminución en la germinación al incrementar la profundidad de siembra y la oscuridad así como mantener el potencial osmótico por debajo de −0.4 MPa Sin embargo, la germinación en ambos tipos no fue afectada por la variación del pH de 4.0 a 9.0. Basado en las condiciones climáticas y de suelo en las Islas Penghu, es razonable predecir que la estación de verano en la cual las semillas de *Leucaena leucocephala* (Lam.) germinan fácilmente sobre la tierra o en suelos poco profundos, es la temporada óptima para controlar esta planta.

Lead tree, formerly known as *Leucaena glauca*, is a thornless long-lived shrub or tree that may grow to a height of 7 to 18 m. Leaves are bipinnate with 6 to 8 pairs of pinnae bearing 11 to 23 pairs of leaflets 8 to 16 mm long. The inflorescence is a cream-colored globular shape that produces a cluster of flat brown pods 13 to 18 mm long containing 15 to 30 seeds. Botanically, leucaena belongs to family Mimosaceae and is the best known species of *Leucaena* genus. However, at least 14 other species have been recognized in this genus (Shelton and Brewbaker 1994). This plant has its origins in Central America and the Yucatan Peninsula of Mexico where its fodder value was recognized over 400 yr ago by the Spaniards, who carried leucaena feed and seed to the Philippines to feed their livestock (Brewbaker et al. 1985). In 1643, the Dutch brought this exotic plant to Taiwan (Chen 2003). At the end of the 19th century, the Japanese introduced it as windbreak forest, fuel, and livestock forage into Penghu Islands, and lead tree plants are now widespread in this archipelago, which is 140 km off the western coast of Taiwan (Chen 2003). Penghu Islands, consisting of one major island and more than 90 small islands, are separated from Taiwan Island (total area

DOI: 10.1614/WT-D-10-00042.1
* Graduate Student, Assistant Researcher, Lecturer, and Professor, respectively, Department of Agronomy, National Chung-Hsing University, 250 Kuokuang Road, Taichung, Taiwan. Current address of second author: Division of Plant Toxicity, Taiwan Agricultural Chemicals and Toxic Substances Research Institute, Council of Agriculture, Wufeng, Taichung County, Taiwan. Current address of third author: Center of General Education, Central Taiwan University of Science and Technology, Taichung County, Taiwan. Corresponding author's E-mail: cywang@nchu.edu.tw

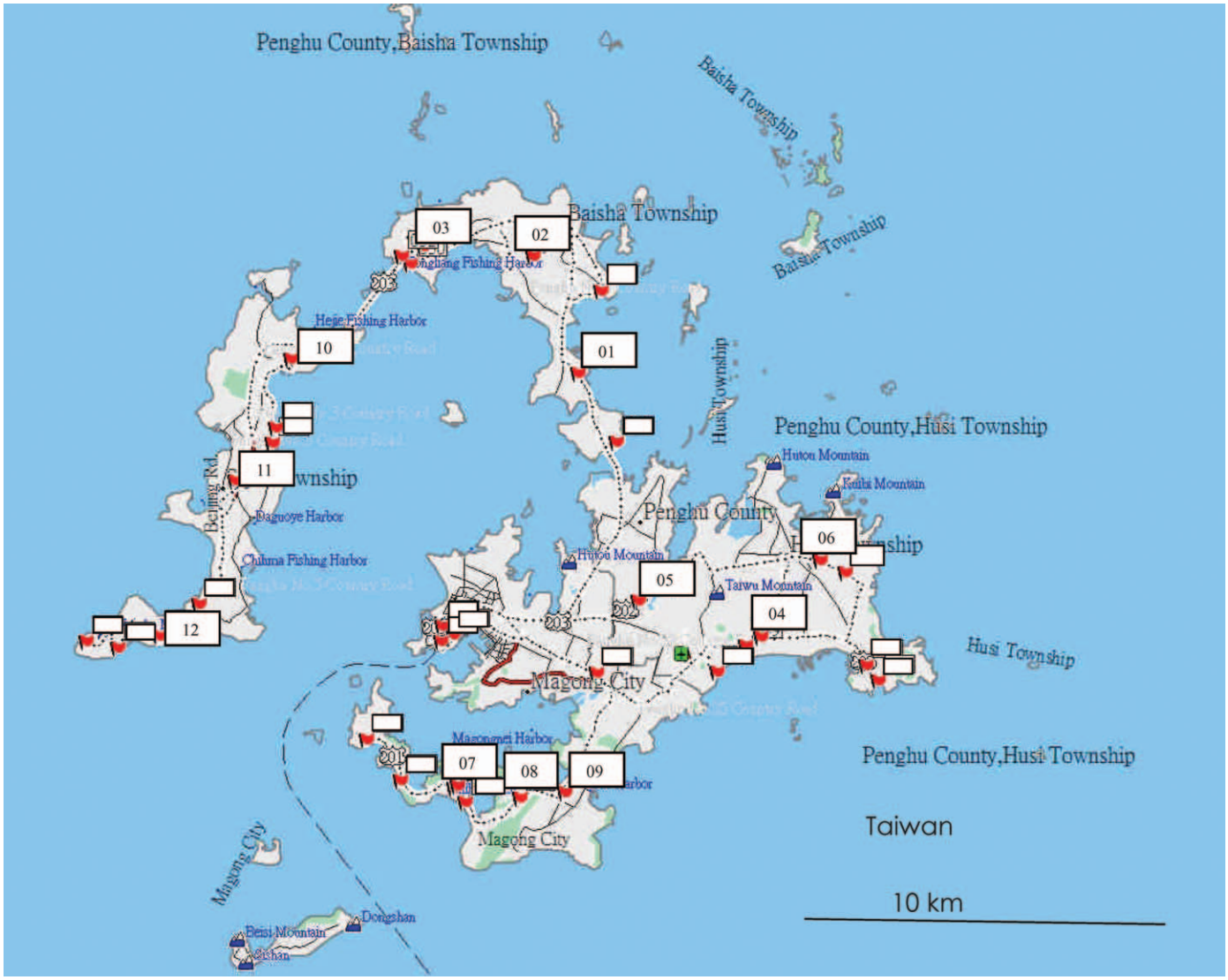


Figure 1. Survey sites of lead tree forest at Baisha, Husi, Magong, and Siyu in Penghu Islands of Taiwan. Code numbers are shown in Table 1.

36,188 km^2) by Taiwan Strait. The climate in Penghu Islands is similar to that in southern Taiwan, with monthly average temperatures of 22 to 23 C, a rainfall of 1,500 mm per year, high light intensity, and strong sea wind. Because of the limited land area and rainfall, water supply is always insufficient for plant growth in Penghu Islands.

Although lead tree varies widely from small shrubs to handsome trees, there are only two types in Taiwan: Hawaii shrub type, which has a good adaptability to stressed environments and commonly grows to 5 m tall, and Salvador type, which is a 20-m giant arbor plant type (Lee 2005). In the Hengchun Peninsula of southern Taiwan, we found only a few plants of Salvador type near Kuansan village; more than 95% of the lead trees there were Hawaii type. Yet, the isolated geographic location of the Penghu Islands might allow this exotic plant to exhibit adaptations different from those in Hengchun Peninsula, Taiwan (Chen et al. 2008).

The nearly pure forest flora of this lead tree species in southern Taiwan has displaced many indigenous forest species and created a need for native vegetation restoration. The high temperature and abundant insolation in summer as well as strong winds in winter of Penghu Islands are detrimental even to the growth of most indigenuous plants, and yet, the lead tree plants thrive. Since the commercial uses of this plant have diminished with time, local authorities are obliged to divert their attention to the adverse effects of this plant to biodiversity. The objective of this study was to determine the current distribution and growth of lead tree in the Penghu Islands and estimate the seed germination potential of both types under conditions simulating the stressed environment of Penghu Islands.

Materials and Methods

Distribution and Growth of Lead Tree in Penghu Islands. The distribution of lead tree plants in four administrative regions, including Baisha, Husi, Magong, and Siyu, was surveyed. The total land area of Penghu Islands (Figure 1) is

https://doi.org/10.1614/WT-D-10-00042.1 Published online by Cambridge University Press

Table 1. Basic geographic information of sampling locations of lead tree forest in Penghu Islands, Taiwan.

Region	Sample location	GPS[a] address	Code number[b]
Baisha	1	23°37.772′N, 119°36.106′E	01
	2	23°39.508′N, 119°35.398′E	02
	3	23°39.650′N, 119°33.623′E	03
Husi	1	23°33.866′N, 119°39.066′E	04
	2	23°34.401′N, 119°37.084′E	05
	3	23°34.999′N, 119°40.019′E	06
Magong	1	23°31.679′N, 119°34.166′E	07
	2	23°31.504′N, 119°35.173′E	08
	3	23°31.577′N, 119°35.904′E	09
Siyu	1	23°37.984′N, 119°31.493′E	10
	2	23°36.189′N, 119°30.598′E	11
	3	23°33.891′N, 119°29.379′E	12

[a] Abbreviation: GPS, global positioning system.

[b] Code number of sampling location in lead tree forest appears in Figure 1.

127 km^2, and about 40% of this area has been covered with lead tree (Chen and Lee 2005). Field surveys, with three locations selected for each region (Table 1; Figure 1) and four sampling sites (2 by 2 m) for each location, were carried out in fall (November 2006) and summer (June 2008). Locations were selected randomly and their geographical distribution was separated (Figure 1). These locations, though randomly selected, were chosen with the considerations of representing geographically all Penghu Islands (Figure 1). Survey parameters included plant type, diameter of trunk at 1 m above ground, plant height, plant density, and growth/development stage. Plant height was measured after tree cutting from the base of trunk, and the number of trees in each site, namely density, was counted. In addition, growth stage was recorded and categorized into vegetative, flowering, podding, and depodding stages. To help estimate the seed germination potential of the lead tree under natural environments in Penghu Islands, annual climatic data including temperature in 2007 and monthly precipitation averaged from 2006 to 2008 were obtained from the website of the Central Weather Bureau (2010), soil pH values of all sites from the same location were combined, and then data from three locations were pooled for each region.

Germination Potential of Lead Tree. Seeds of the Hawaii type and Salvador type were collected, respectively, from Penghu Island and Hengchun Peninsula of southern Taiwan in fall 2000. They were air-dried at 28 C and kept at 4 C for long-term storage. Seed germination of both Hawaii and Salvador types was recorded 1, 3, 5, 7, and 14 d after incubation at different temperatures. For treatments of different pH, osmotic potential, soil burial depth, and lighting, seed germination was recorded 14 d later to account for possible delay of the process. Three independent experiments with three replicates consisting of 20 seeds for each type were conducted. Since the seed germination rate of this plant had been shown to be consistent with little variation in a preliminary experiment, a relatively small number of seeds for each replicate, i.e., 20, was used in this study. Seed germination was defined as the penetration of the radicle through the seed coat and seedling emergence was defined as the appearance of seedlings on soil surface.

Temperature. Seeds of both lead tree types were placed in petri dishes lined with filter paper[1] prewet with 5 ml of distilled water, and then all dishes were sealed with parafilm[2] and incubated in the dark at seven temperatures (10, 15, 20, 25, 30, 35, and 40 C). Seed germination percentage was recorded 1, 3, 5, 7, and 14 d after treatment (DAT).

pH. Seeds were incubated in petri dishes as in the temperature experiment. Buffer solutions with pH values ranging between 4.0 and 9.0 were applied on filter paper in these dishes instead of distilled water. A 2 mM potassium hydrogen phthalate[2] buffer solution was adjusted to pH 4.0 with 1 N HCl and a 2 mM 2-(*N*-morpholino)ethanesulfonic acid[3] buffer solution was adjusted to pH 5.0 and 6.0, respectively, with 1 N NaOH. Besides, the pH 7.0 and 8.0 buffer solutions consisting of 2 mM *N*-(2-hydroxymethyl)-piperazine-*N*-(2-ethanesulfonic acid)[3] were adjusted with 1 N NaOH, and the pH 9.0 buffer solution of 2 mM *N*-tris(hydroxymethyl) methyl glycine was adjusted with 1 N NaOH (Chachalis and Reddy 2000). In view of the monthly changes in air temperature in Penghu Islands (Figure 3A), petri dishes were placed in an incubator at 30 C and seed germination was recorded 14 DAT. Soils collected within and outside of the lead tree forest at three locations of four administrative regions in Penghu Islands were air-dried at 28 to 30 C for 1 wk, and their pH values were measured after mixing soil samples with an equivalent amount of distilled water (1 : 1, w/v).

Osmotic Potential. Seeds were incubated in petri dishes as in the temperature experiment. Osmotic solutions with osmotic potentials of −0.2, −0.4, −0.6, −0.8, and −1.0 MPa were prepared by dissolving 154, 191, 230, 261, and 297 g of polyethylene glycol (PEG) 8000,[4] respectively, in distilled water made up to 1 L (Smith et al. 1992), and then applied on filter paper in dishes. Petri dishes were placed in an incubator at 30 C and seed germination was recorded 14 DAT.

Lighting. Seeds were incubated in petri dishes as in the temperature experiment. Dishes were either wrapped with aluminum foil to prevent light penetration or placed under an artificial light of 315 μmol m^{-2} s^{-1} at 30 C for 14 d. To exclude the light effect, germination observation of dark-treated seeds was carried out rapidly every 3 d under the weak red light in dark room.

Burial Depth. Seeds were sown in black plastic pots (9 cm diam, 10 cm high) filled with clay and loamy soils (3 : 1, v/v) that had passed through a 3-mm sieve; planting depths tested were 0, 1, 2, 3, 4, and 5 cm. In this experiment, a 5-cm soil layer in pot was prepared first, then seeds were sown on the soil surface; afterward a 1-cm soil layer was added and pressed tightly before the second sowing. This procedure was repeated in different pots so as to have seeds buried at five different depths. Pots were placed in the greenhouse at 30 C for 14 d, and seedling emergence was recorded.

Seed Size and Mass of Two Plant Types. Seeds of Hawaii- and Salvador-type lead tree plants, which are readily distinguishable from their appearance, were collected, respectively, from Penghu Islands and Henghcun Peninsula near Kuasan village of southern Taiwan. Grown lead tree plants, 10 yr old or more, were chosen to avoid possible misidentification. After

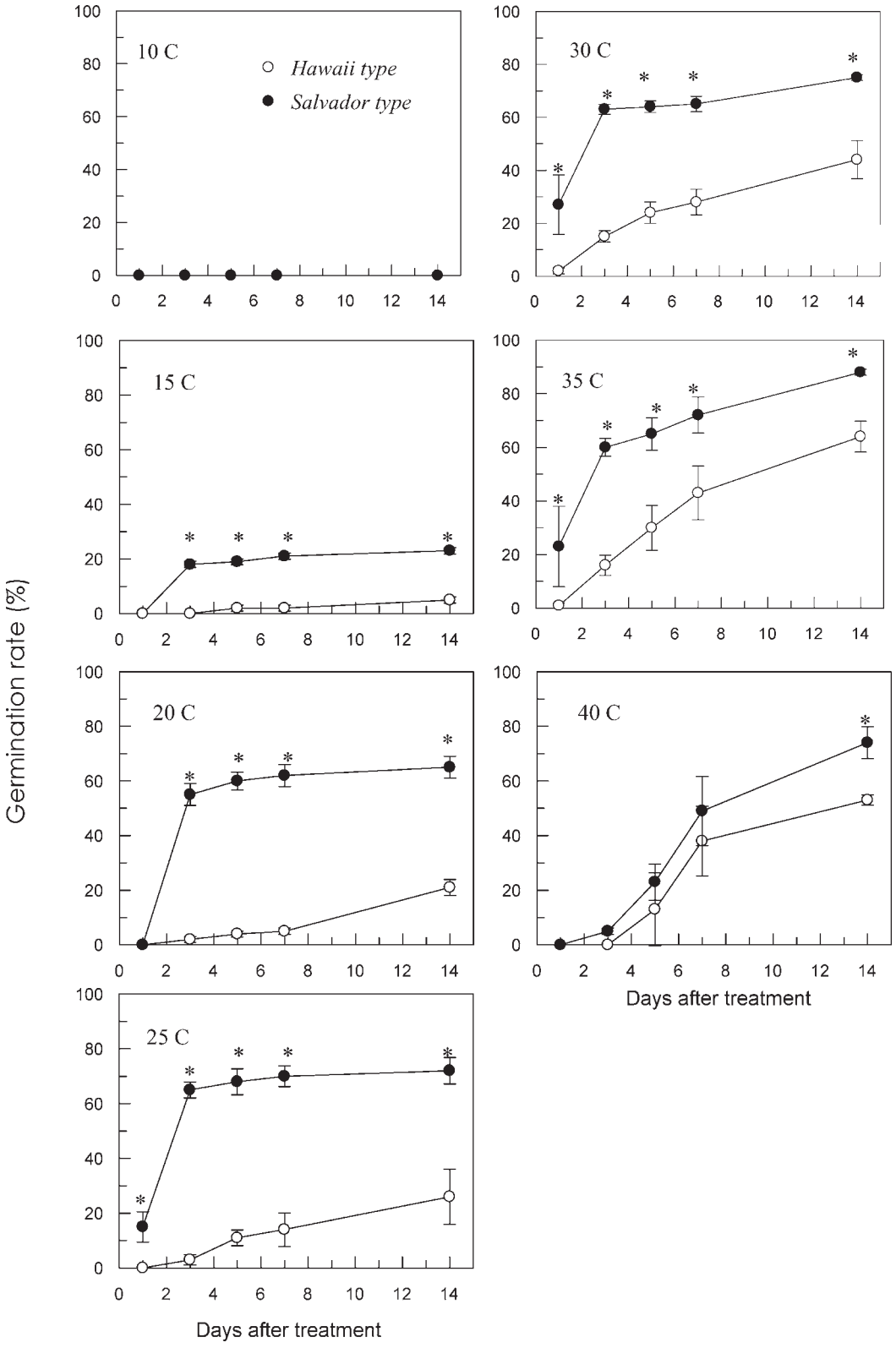


Figure 2. Changes in seed germination rate for Hawaii and Salvador types of lead tree with time after treatments at different temperatures. Asterisks indicate a significant difference between two plant types at any time recorded on the basis of one-way ANOVA at alpha level of 0.05. Vertical bars are standard errors of the mean.

https://doi.org/10.1614/WT-D-10-00042.1 Published online by Cambridge University Press

Table 2. Distribution and growth stage of lead tree[a] in Penghu Islands, Taiwan, in fall (November 2006).

Region	Location	Girth of trunk[b]	Plant height	Growth stage
		cm	m	
Baisha	1	3.13 ± 0.08[c]	3.09 ± 0.22	Flowering–depodding
	2	4.03 ± 1.18	3.63 ± 0.55	Podding–depodding
	3	2.30 ± 0.40	2.30 ± 0.38	Podding–depodding
	Mean	3.15	3.01	
Husi	1	2.76 ± 0.26	3.02 ± 0.12	Vegetative–depodding
	2	2.08 ± 0.18	2.74 ± 0.22	Podding–depodding
	3	2.22 ± 0.14	3.43 ± 0.33	Podding
	Mean	2.35	3.06	
Magong	1	3.34 ± 0.88	2.59 ± 0.23	Podding–depodding
	2	2.89 ± 0.23	3.21 ± 0.27	Podding–depodding
	3	2.96 ± 0.28	3.23 ± 0.37	Flowering–depodding
	Mean	3.06	3.01	
Siyu	1	2.53 ± 1.03	2.60 ± 0.88	Podding–depodding
	2	2.33 ± 0.45	2.73 ± 0.53	Podding–depodding
	3	3.01 ± 0.28	3.20 ± 0.13	Podding
	Mean	2.62	2.84	
P value (comparison among four regions)		0.26	0.94	

[a] The only plant type found in Penghu Island was Hawaii type.

[b] Measurement made at 100 cm above ground.

[c] Mean and standard deviation with four sampling sites (area 2 × 2 m^2).

air-drying for 1 wk, the size and weight of 300 seeds for each type were measured.

All experiments utilized a completely randomized design and were conducted three times, with each treatment replicated at least three times. Data were analyzed with Microsoft Excel software[5] and presented as the mean and standard error of the sample mean (SEM). The latter was calculated on the basis of the equation SEM = (standard deviation [STDEV][range of values]/square root [SQRT][count{range of values}]) in Excel program. Means were separated with Fisher's Protected LSD at the alpha level of 0.05.

Results and Discussion

Distribution and Growth of Lead Tree in Penghu Islands. *Field Survey of Lead Tree in Fall 2006.* Survey results within four administrative areas including 36 locations (Figure 1 with red flag marks) showed that the Hawaii type was the sole kind of lead tree in Penghu Islands, with 2- to 4-cm diam of trunk at 1-m height and a height of 2 to 4 m (data of 12 of 36 locations shown in Table 2). We did not find any lead tree plants with characteristics of Salvador type in the other 24 locations (data not shown). The Hawaii-type perennial shrub

Table 3. Distribution and growth stage of lead tree[a] in Penghu Islands, Taiwan, in summer (June 2008).

Region	Location	Girth of trunk[b]	Plant height	Growth stage	Plant density
		cm	m		no. (4 m)$^{-2}$
Baisha	1	3.31 ± 0.20[c]	3.89 ± 0.13	Vegetative–podding	20
	2	3.49 ± 0.37	3.84 ± 0.25	Vegetative–podding	22
	3	2.59 ± 0.21	3.28 ± 0.12	Vegetative	20
	Mean	3.13	3.67		21
Husi	1	2.92 ± 0.19	2.97 ± 0.09	Vegetative	18
	2	2.54 ± 0.18	2.98 ± 0.07	Vegetative	20
	3	2.55 ± 0.24	2.90 ± 0.09	Vegetative	12
	Mean	2.67	2.95		17
Magong	1	2.21 ± 0.24	2.95 ± 0.17	Vegetative–podding	19
	2	2.53 ± 0.15	2.83 ± 0.10	Vegetative	14
	3	2.05 ± 0.09	2.14 ± 0.08	Vegetative	12
	Mean	2.26	2.64		15
Siyu	1	3.93 ± 0.27	3.11 ± 0.09	Vegetative–podding	19
	2	3.13 ± 0.29	3.99 ± 0.19	Vegetative–podding	22
	3	2.88 ± 0.22	4.74 ± 0.20	Vegetative–podding	16
	Mean	3.31	3.94		19
P value (comparison among four regions)		0.046	0.044		0.22
$LSD_{0.05}$		0.65	0.81		

[a] Lead tree found in Penghu Islands was Hawaii type.

[b] Measurement made at 100 cm above ground.

[c] Mean and standard deviation with four sampling sites (area 2 × 2 m^2).

https://doi.org/10.1614/WT-D-10-00042.1 Published online by Cambridge University Press

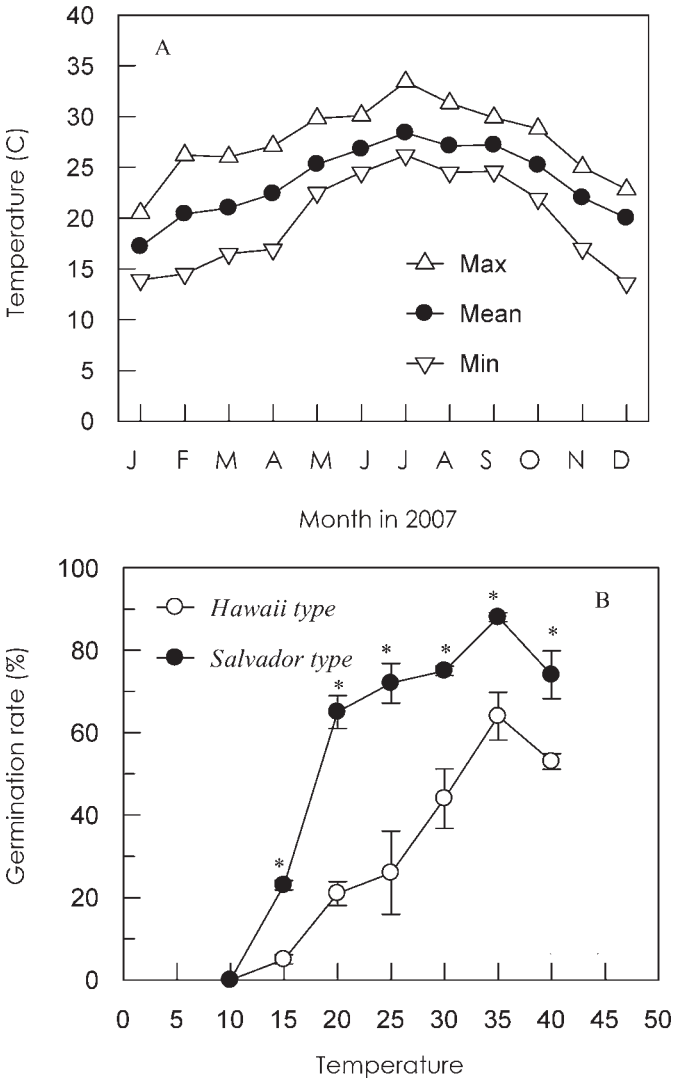


Figure 3. (A) Changes in monthly average temperature at Penghu Islands of Taiwan in 2007, and (B) effect of temperature on seed germination for Hawaii and Salvador types of lead tree. Germination rate was measured 14 d after treatment. Asterisks indicate a significant difference between two plant types at any temperature on the basis of one-way ANOVA at alpha level of 0.05. Vertical bars are standard errors of the mean.

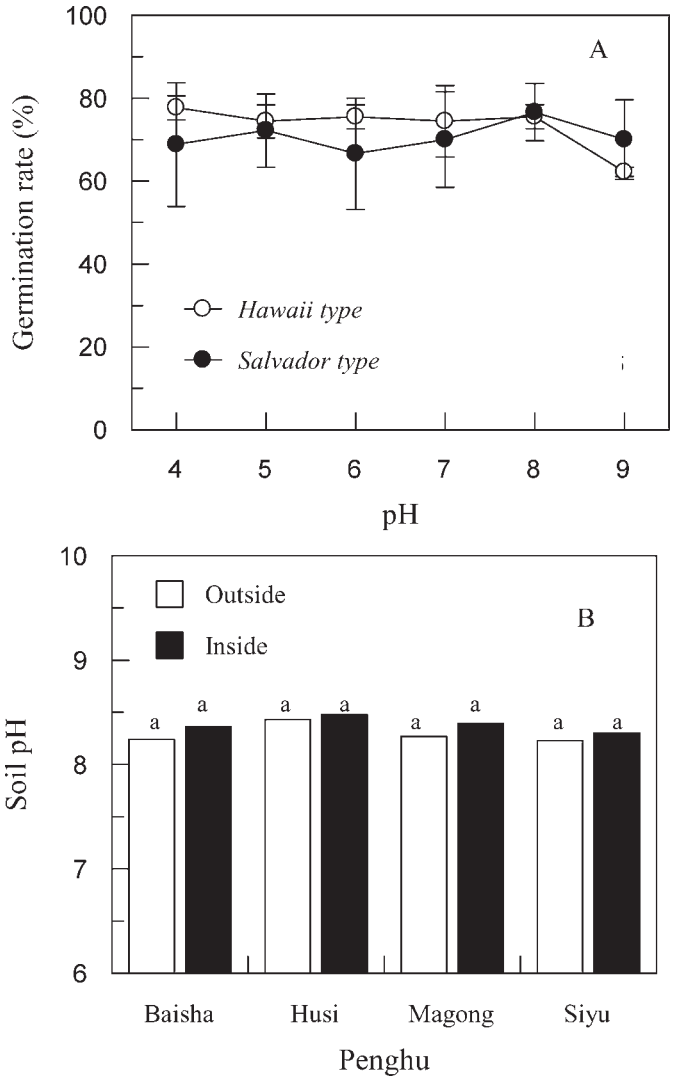


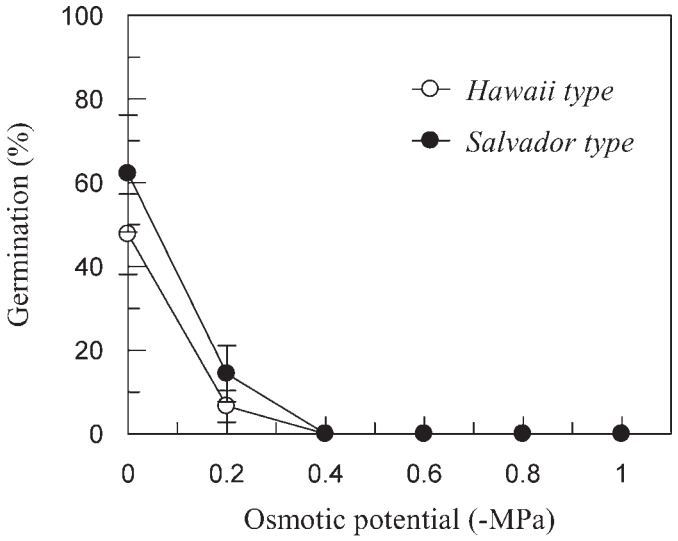
Figure 4. (A) Effect of pH on seed germination for Hawaii and Salvador types of lead tree plant. There is no significant difference between two plant types at any pH treatments on the basis of one-way ANOVA at alpha level of 0.05. Vertical bars are standard errors of the mean. Germination rate was measured at 14 d after pH treatment, and (B) soil pH values outside (□) and inside (■) of lead tree forest at four locations in Penghu Islands. Vertical bars with the same letter are not significantly different on the basis of Fisher's Protected LSD test at 0.05 level.

has formed a pure forest since the last century. In fall season when the weather in Penghu Islands is typically dry and windy, some lead trees were in vegetative and flowering stages, but more were in podding and depodding stages. Afterward, most leaves and pods dropped. Lead tree plants with fewer leaflets to reduce transpiration in this season might be advantageous for it to cope with the arid environment of these islands. Lee (2005) reported that the Hawaii-type lead tree has good adaptation ability to stressed environments, especially to drought conditions.

Field Survey of Lead Tree in Summer 2008. A survey in the summer season showed that the Hawaii type was still the only type of lead tree in Penghu Islands, with 2- to 4-cm diam of trunk at 1-m height and 2 to 4 m of plant height (Table 3). However, possibly due to the humid and warm climate without strong sea wind in this period, the lead tree was found mostly in the vegetative stage showing vigorous growth of branches and leaflets, with some plants having reached the podding stage. Average lead tree plant density ranged from 12 to 22 plants per 4 m^2 area, with no significant difference among the four administrative locations surveyed (Table 3).

Field investigation of lead tree plants in two different seasons within a 1.5-yr interval showed a continuous existence of this exotic plant species in the Penghu Islands. Lead tree plants usually remained in a vigorous vegetative stage in summer and a podding stage with fewer leaflets in late fall to adapt to the adverse environment. In the harsh environment during fall and winter seasons in Penghu Islands, the strong salty sea wind and drought restricted the growth of this plant, which generally maintained a height of 2 to 4 m, lower than

https://doi.org/10.1614/WT-D-10-00042.1 Published online by Cambridge University Press



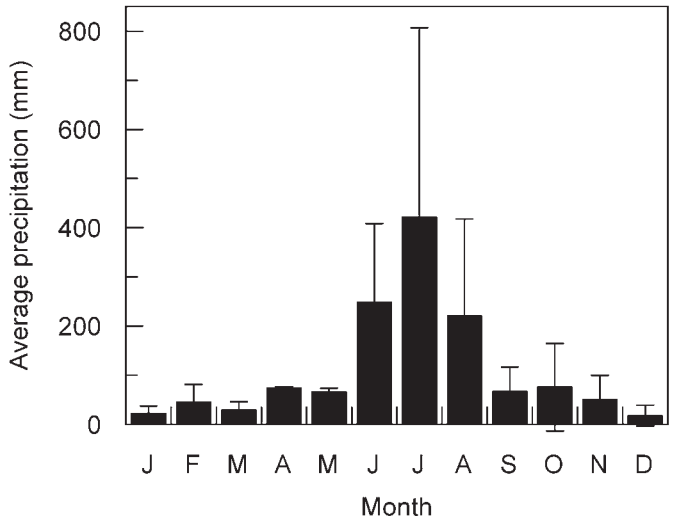


Figure 5. Effect of osmotic potential in culture medium on seed germination for Hawaii and Salvador types of lead tree. Germination was measured at 14 d after treatment, and change of monthly average precipitation in Penghu of Taiwan from 2006 to 2008 is shown. There is no significant difference between two plant types at any osmotic potentials on the basis of one-way ANOVA at alpha level of 0.05. Vertical bars are standard errors of the mean.

that of 6 to 7 m on the lee side in Hengchun Peninsula, Taiwan, as we observed before (data not shown).

Seed Germination Potential of Lead Tree in Penghu Islands. *Temperature.* Although no seeds of Salvador-type lead tree germinated at 10 C by 14 d after initiation (DAI), about 20% germination was observed from 3 to 14 d at 15 C (Figure 2). Within the temperature range of 20 to 35 C, seed germination rate reached and maintained 60% 3 DAI except at 35 C, and at the latter temperature the seed germination rate increased to 80% 14 DAI. At 40 C, seed germination was delayed and decreased. On the other hand, seed germination of the Hawaii type was slower and lower than that of Salvador type (Figures 2, 3B), reaching a maximum of only 60% 14 DAI at 35 C.

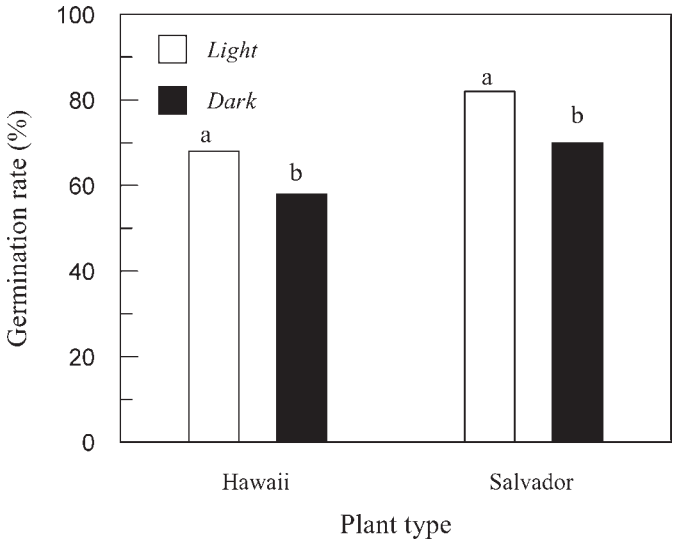


Figure 6. Effect of light on seed germination for Hawaii and Salvador types of lead tree. Germination was measured at 14 d after treatment. Bars with different letters within the same plant type are significantly different on the basis of Fisher's Protected LSD test at alpha level of 0.05.

Monthly temperature changes in Penghu Islands showed that the highest temperature in July was 33.4 C and the lowest temperature in January was 13.9 C (Figure 3A). Therefore, it is reasonable to state that the Hawaii-type seed is able to germinate year-round in the Penghu Islands, with its maximum germination rate in the summer. Cooksley et al. (1988) reported that lead tree growth is strongly seasonal in the subtropics, with low yields in the cool months and the majority of growth occuring in the summer months. In our study, summer temperatures were more suitable for lead tree seed germination than in other seasons, especially for the Salvador-type plant.

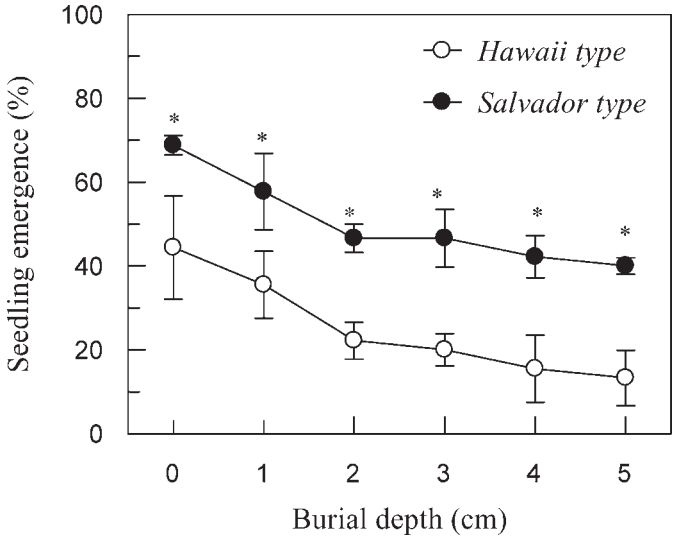


Figure 7. Seedling emergence for Hawaii and Salvador types of lead tree 14 d after sowing in different burial depths. Asterisks indicate a significant difference between two plant types at any burial depths on the basis of one-way ANOVA at alpha level of 0.05. Vertical bars are standard errors of the mean.

https://doi.org/10.1614/WT-D-10-00042.1 Published online by Cambridge University Press

Table 4. Size and mass of seeds for Hawaii- and Salvador-type lead tree plants used in seed germination experiment.

Plant type	Source[a]	Seed size			Seed mass
		Length	Width	Thickness	
		mm			g 1,000 seeds^{-1}
Hawaii	Penghu Islands	6.28	4.13	1.33	37.65
Salvador	Pington County, southern Taiwan	7.34	4.70	1.43	53.85
P value		< 0.01	0.010	0.27	< 0.01

[a] All seeds were harvested from the pods of adult tree plant, with age at least 10 yr, during fall when the pod color turned deep brown.

pH. Germination of both Salvador- and Hawaii-type seed was 65 to 75% 14 DAI across pH levels of 4 to 9 (Figure 4), indicating that seeds of both types had a wide adaptation ability to different pH environments. Soils collected within and outside of lead tree forest at four administrative regions in Penghu Islands had pH from 8.2 to 8.5 (Figure 4). Therefore, it is believed that seeds of the Hawaii type can readily germinate in somewhat alkaline soils in these islands. It may be worthwhile to mention that seeds of lead tree were found to have high adaptation as well to acidic environment in an experiment mimicking an acid-rain situation (Shaukat and Shafiq 1998).

Osmotic Potential. Seed germination of both Salvador- and Hawaii-type lead tree plants 14 DAT was lowered with a decreasing osmotic potential from 0.0 to −0.4 MPa; no germination was observed at values lower than −0.4 MPa (Figure 5), indicating a high water requirement of lead tree for seed germination. With an average precipitation of ca. 270 mm during the summers of 2006 to 2008 in Penghu Islands, it is reasonable to state that summer seasons with the most abundant rainfall are optimal times for lead tree seeds to germinate. Brewbaker et al. (1985) reported that lead tree can be found performing well in a wide range of rainfall environments from 650 to 3,000 mm. However, yields are low in dry environments and are believed to increase linearly from 800 to 1,500 mm of rainfall (Brewbaker et al. 1985). Although it is unclear why lead tree plants have higher adaptability than other plant species to the stressed environment in Penghu Islands, young seedlings have shown high drought tolerance during establishment and can survive extended periods of dry weather (Shelton and Brewbaker 1994).

Light. Although 60 to 80% of the seeds germinated by 14 d with or without lighting, a consistent higher rate of seed germination in light than in dark for both types of lead tree plants (Figure 6) suggests a partial requirement of light for this process.

Burial Depth. After 14 d, seedlings emerged from 70% of the Salvador-type seeds placed directly on the soil surface; and emergence decreased with increasing burial depth of the the seeds in the soil (Figure 7). The Hawaii type showed a similar and yet lower trend of seedling emergence (Figure 7). This difference may be related to the fact that seeds of the Salvador type are considerably larger and heavier than those of the Hawaii type (Table 4). Akinola et al. (1999) also reported that seedling emergence rate of Peru-type lead tree was higher when seeds were sown shallow. Considering results of the lighting experiment (Figure 6), it is reasonable to suggest that light deficiency in deep soil environments might partly account for ca. 10% decrease of seedling emergence through inhibition of seed germination. In view of the extent of the decrease of seedling emergence with the depth of soil covering the seeds, some other soil factors must have been involved as well.

In conclusion, although only the Hawaii-type lead tree has been found in Penghu Islands up to date, seeds of both Hawaii and Salvador types are able to germinate in these islands. Although soils in Penghu Islands are relatively poor, the warm and humid weather in summer still allows the seedlings to establish; and then, the strong sea wind in winter would cause most leaves to fall. After the plant escapes from this difficult season, its leaves would then regrow in the middle part of the canopy. Thus, the lead tree would maintain low stature, a morphology distinctly different from that of this plant in southern Taiwan. Since the seeds of this plant readily germinate under the natural environment in Penghu Islands, especially from June to August, it is therefore recommended that summer is the best time to control lead tree propagation because after that, seed germination would commence.

Sources of Materials

[1] Filter paper 5C, 9 cm in diam, Toyo Roshi Kaisha, Ltd., Tokyo, Japan.

[2] PM-996, Pechiney Plastic Packaging, Menasha, WI 54952.

[3] Sigma Chemical Co., P.O. Box 14508, St. Louis, MO 63178.

[4] PEG 8000, Riedel-de Haën, Kufstein, Austria.

[5] Software of Microsoft Co., Redmond, WA 98052-7329.

Acknowledgment

The authors thank Prof. C. N. Sun, Department of Entomology, National Chung-Hsing University, for her kind encouragement and suggestions for improvements to this manuscript.

Literature Cited

Akinola, J. O., P. A. Iji, S. O. Bonidefaiye, and S.A.S. Oloruniu. 1999. Studies on seed germination and seedling emergence in *Leucaena leucocephala* (Lam.) de Wit cv. Peru. Seed Sci. Technol. 27:123–129.

Brewbaker, J. L., N. Hegde, E. M. Hutton, R. J. Jones, J. B. Lowry, F. Moog, and R. van den Beldt. 1985. Leucaena—Forage Production and Use. Nitrogen Fixing Tree Association, Hawaii. 39 p.

Central Weather Bureau. 2010. Daily precipitation. Ministry of Communication, Executive Yuan, Taiwan. http://www.cwb.gov.tw/V6/statistics/dailyPrecipitation/dP.php. Accessed: May 17, 2010. [In Chinese]
Chachalis, D. and K. N. Reddy. 2000. Factors affecting *Campsis radicans* seed germination and seedling emergence. Weed Sci. 48:212–216.
Chen, K. L. 2003. Promotion of Forestry Establishment on Farm Land Utilization Fundamental Way to Control Lead Tree. Penghu, Taiwan: Agriculture and Fisheries Bureau, Penghu County Government, Taiwan.
Chen, R. F., H. H. Wang, and C. Y. Wang. 2008. Dissipation of glyphosate injected into the lead tree (*Leucaena leucocephala* L.) in different seasons in Taiwan. Taiwan J. For. Sci. 23:375–387.
Chen, Z. H. and Z. M. Lee. 2005. Using GIS to analyze characters of plant vegetation distribution in Penghu area. The Third Symposium of Land Research—Territory Plan and Sustainable Management. Feng-Chai University, Taichung, Taiwan. [in Chinese]
Cooksley, D. G., J. H. Prinsen, and C. J. Paton. 1988. *Leucaena leucocephala* production in subcoastal south-east Queensland. Trop. Grass. 22:21–26.
Lee, P. F. 2005. Exotic plants. Pages 152–159 *in* P. F. Lee, ed. Green Land—Natural Resources and Ecology GIS Database in Taiwan. Taipei, Taiwan: Forestry Bureau, Council of Agriculture, Executive Yuan. [Official publication in Chinese]
Shaukat, S. S. and N. Shafiq. 1998. Effects of simulated acid rain on germination and seedling growth of some wild and cultivated species. Rak. J. Biol. Sci. 1:219–222.
Shelton, H. M. and J. L. Brewbaker. 1994. *Leucaena leucocephala*—the most widely used forage tree legume. Pages 15–29 *in* R. C. Gutteridge and H. M. Shelton, eds. Forage Trees as Legumes in Tropical Agriculture. Wallingford, CT: CAB International.
Smith, C. A., D. R. Shaw, and L. J. Newsom. 1992. Arrowleaf sida (*Sida rhombifolia*) and prickly sida (*Sida spinosa*): germination and emergence. Weed Res. 32:103–109.

Received March 11, 2010, and approved June 7, 2010.