Emergence and seedling survival of leucaena on poorly drained soil and management practices to mitigate negative effects

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Abstract

Leucaena (*Leucaena leucocephala*) has potential in Florida as a pasture legume, but soils are often imperfectly drained making establishment difficult. We conducted 2 glasshouse studies to determine responses of 8 leucaena and 1 *Calliandra calothyrsus* selection to different soil moisture conditions. In the first, freely drained and waterlogged soils were compared. In freely drained soil, seedling emergence was greater for leucaena (78–93%) than for calliandra (53%), but in waterlogged soil emergence of all entries was depressed (3–20%). In the second, 4 water regimens were compared: maintaining water level at 3 cm above the soil surface; at the soil surface; and 15 cm below the soil surface; and as freely draining soil. Water level at 15 cm below the soil surface gave best seedling growth. Water at or above the surface induced aerenchyma on stem bases, which enabled persistence under waterlogging.

A field study examined the effects of bedding (raised and flat), propagule (seed and seedlings) and time of planting [July (during) and October (after rainy season)] on seedling survival of 5 leucaena selections. Leucaena K636 and K340, with >80% survival, established well in July or October with seed or seedlings, but K749, K784 and LxL, with 63–70% survival, established best in October with seedlings. Results demonstrate that bedding may not improve survival of leucaena seedlings during high rainfall periods, with propagule, selection and time of planting being more important.

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Introduction

Soils of central and south Florida, where ~80% of the state's cattle are raised, are predominantly Spodosols. These are sandy, infertile, nearly level and seasonally poorly drained due to the impervious Spodic horizon, a weakly cemented layer of sand with organic coatings. Rainfall in the region is ~1400 mm annually, 60% of which is received in July–September. Rainfall averaging 1.1 cm/d in the summer allows water to accumulate and eventually flood these Spodosols (Dantzman and McCaleb 1969).

Beef cattle gains on bahiagrass (*Paspalum notatum*), the major pasture grass, decline in summer commensurate with the reduction in nutritive value at this time (Prates *et al.* 1975; Sollenberger *et al.* 1987; Williams *et al.* 1991). Forage legumes provide nutritious forage to supplement bahiagrass and can improve cattle productivity in summer (Rusland *et al.* 1988; Pitman *et al.* 1992). *Leucaena* spp. (leucaena) are tropical forage tree legumes that can be productive, nutritious and dependable for grazing in south Florida (Othman *et al.* 1985; Austin *et al.* 1995; Kalmbacher *et al.* 2001). However, field establishment of leucaena sown in summer is poor because of excessively wet soil. In general, leucaena is not adapted to poorly drained soils (Brewbaker 1987; Hughes 1998). However, leucaena will survive and grow on poorly drained soil in Florida if plants survive to about 2–3 months of age. Options for overcoming poor soil drainage include identification of adapted selections, use of transplanted seedlings in lieu of seed, planting at times of lower precipitation and the use of plant beds.

Large variation exists among legume selections for yield and survival on poorly drained soil (Miller and Williams 1981; Whiteman *et al.* 1984). There are also indications that new selections of *L. leucocephala*, its hybrid with other species, or new species from areas that experience seasonally high rainfall may be adapted to wet soils (Miller and Williams 1981; Hughes 1998). Gilbert *et al.* (1993) reported that *L. leucocephala* cv. Cunningham was among the best legume entries grown on wet soil. According to Brewbaker (1976), there are certain strains of leucaena with known tolerance to wet soils in Thailand, so selection of tolerant strains seems feasible.

The use of transplanted seedlings by-passes problems associated with germination, emergence and seedling establishment. Transplanted seedlings resulted in greater success in field establishment than direct seeding (Shelton 1994). Planting before or after periods of excessive rainfall may permit leucaena to grow and establish when the soil is not waterlogged. Since leucaena is drought-tolerant even at the seedling stage (Shelton and Brewbaker 1994), conditions created by low rainfall may be less problematic than conditions created by excessive rainfall.

Tillage offers the possibility of modifying the soil environment and reducing negative effects associated with wet soil. For many years, vegetables in Florida have been planted on 65-cm-wide ridges or beds with shallow ditches at intervals of 20 to 30 rows (Smith 1956). While this practice has not been widely reported for leucaena, it may prove to be practical.

To further define the effects of poor soil drainage on leucaena and to identify strategies to overcome its problems, we conducted 2 glasshouse experiments to determine the effect of different soil moisture conditions on emergence and seedling survival of 8 leucaena and 1 calliandra selections. A field study compared the effects of bedding treatments (raised and flat), propagule (seed and seedlings) and time of planting (July, during; and October, after rainy season) on the survival of seedlings of 5 leucaena selections.

Materials and methods

Glasshouse trials

Two experiments were conducted in a glasshouse in which the mean daytime temperature was 30–35°C. Experiment 1 was conducted in October–November 2002, and repeated in April 2003. Experiment 2 was conducted in October 2002–May 2003.

Experiment 1. Seedling emergence and survival of leucaena on a poorly drained soil.

The A horizon (0–30 cm) of a Myakka fine sand (sandy, siliceous, hyperthermic Aeric Alaquod) with pH 4.6 was obtained from a native site at the University of Florida Range Cattle Research and Education Center (27°26′N, 81°55′W). After sieving (1.3 cm mesh), the equivalent of 8 tonnes/ha dolomite, 25 kg/ha P, 93 kg/ha K, 2.8 kg/ha Cu, Fe, Mn, Zn as sulphates, and 5.6 kg/ha elemental S were mixed in the soil. Thereafter, 4.5 kg of air-dried soil was weighed into pots (16 cm diameter) and saturated with deionised water. The soils were incubated for 30 d to permit the dolomite to solubilise and for the soil to equilibrate. The pots, which had drainage holes at the bottom, were watered twice weekly during incubation. After incubation, the soil had pH 6.6, and contained (mg/kg Mehlich-1 extractable) 19 P, 45 K, 542 Ca, 248 Mg, 4.7 Zn, 1.6 Mn, 0.036 Cu, 6.6 Fe, 53.4 Al and 10.4 Na (University of Florida, Soil Testing Laboratory; Mylavarapu and Kennelley 2002).

The experiment was a 2-factor factorial in a completely randomised design with 4 replications. Eight leucaena selections and a calliandra were tested at 2 soil water states (waterlogged and freely drained). Calliandra, a species that is not adapted to poor drainage (Palmer *et al*. 1994), was included as a check (Table 1). Pots for the waterlogged treatment were placed in 3.5-cm-deep saucers filled with water. In both runs of the experiment, 5 pre-germinated seeds (radicle protruding) were sown in each pot. Before sowing, the radicles of the germinated seeds were dipped in *Rhizobium* slurry. Water level in the saucers was maintained by daily addition of water as required while the freely drained pots were watered twice weekly. Gravimetric water content of soil, expressed as percentage of dry soil, averaged 19.1% for waterlogged and 13.6% for freely drained treatments. In each run, the cumulative number of seedlings that emerged by Day 15 after sowing was recorded. Between the 2 runs, the soils dried out over a 4-month period. At the end of the second run, seedlings that had grown in the freely drained pots were subjected to waterlogging for another 15 d, and mortality was monitored.

Data were analysed as a 2-factor factorial following the General Linear Model (GLM) of SAS (SAS 1999). There was no run × selection × soil

Table 1. *Leucaena* spp. selections tested in the greenhouse and field with *Calliandra* spp. as a control.

Selection	Label	OFI/other number[1]	Description[2,3]
1. *L. leucocephala*	K636	CIAT21245	*L. leucocephala* selection with superior yield and cold tolerance. Known as cultivar 'Tarramba' in Australia. Recommended above earlier releases such as Peru, K8, Cunningham and K28.
2. *Leucaena* hybrid	LxL	—	Hybrid based on superior *L. leucocephala* parents K397, K565, K584, K608 and K636. Similar in habit to K636.
3. *L. pallida* × *L. leucocephala* F_2	KX2	CIAT22197	Tetraploid hybrid. Spreading branchy habit; excellent psyllid resistance; some cold tolerance and higher forage yields.
4. *L. leucocephala*	CoSAF	—	*L. leucocephala* (K636) selection by Center of Sustainable Agroforestry (CoSAF), St Leo, Florida. Similar in growth to K636.
5. *L. diversifolia*	K784	85-15	Similar in habit to *L. leucocephala* but more tolerant of acid soils and cooler temperatures.
6. *L. leucocephala*	LC	—	Seed of volunteer plants growing on the banks of Lake Poinsett (28° 20' N, 80° 50' W), near Lone Cabbage Fish Camp, Brevard County, Florida[5].
7. *L. trichandra*	K749	ICRAF03190	Provenance Muguga; has some acid tolerance and naturally occurs in nutrient-poor, acid soils.
8. *L. leucocephala* × *L. pulverulenta*[4]	K340	—	Vigorous hybrid with low mimosine concentration; adapted to cooler and acidic sites[2,6].
9. *Calliandra calothyrsus*	calliandra	—	Adapted to a wide range of soils, including acidic sandy soils, but does not tolerate waterlogging.

[1] OFI = Oxford Forestry Institute; CIAT = Centro International de Agricultura Tropical; ICRAF = International Center for Research in Agroforestry.
[2] Hughes (1998).
[3] Agroforester Tropical Seeds: Seed and Inoculant Catalog 2002.
[4] Brewbaker *et al.* (1985).
[5] Personal observations.
[6] Valencia *et al.* (1996).

water status interaction, so the means averaged over runs were used in the analysis. Statistical differences were declared at $P \leq 0.05$ and PDIFF (LSD) used for separation of means (SAS 1999).

Experiment 2. Effect of soil water status on leucaena survival and growth. Soil from A and E (31–40 cm depth, pH = 4.3) horizons taken from the same site as in Experiment 1 was used. The pots were made from 63-cm long × 13-cm diameter PVC tubes fitted with transparent plastic tubing at the sides to indicate level of water. The amounts of air-dry soil from A and E horizons, that would fill 0–15 and 15–45 cm sections, respectively, of pots, were calculated. Soil preparation and nutrient applications were the same as in Experiment 1. Nutrients were applied to 3 kg of A-horizon soil, which was placed above 10 kg of E-horizon soil. The pots were watered adequately at the beginning and kept moist during a 30-d incubation period. Thereafter, 3 inoculated seeds of each of 8 leucaena selections and 1 calliandra (Table 1), scarified by soaking in sulphuric acid for 35 min, were sown in each pot. Seedlings were thinned to one per pot after 14 d. The seedlings were grown under freely drained conditions until 4 months after planting, when treatments, representing various water levels, were applied. The following water levels in the pots were compared: maintained at 15 cm below the soil surface; at the soil surface; flooded to 3 cm above the soil surface; and freely drained.

Plants were observed for any morphological changes until the final harvest at 6 months after planting. Plant height was measured at 4 weeks and 8 weeks (at harvest) after application of treatments. At harvest, shoots were harvested by cutting at the soil surface. Soil was gently washed off the roots, and shoots and roots were dried at 105°C until constant weight. Data were analysed as a 2-factor (soil water status and leucaena selection) experiment with 3 replications. Data analysis and mean separation were as in Experiment 1.

Field trials

Experiment 3. Effect of sowing time, bedding and propagule on field establishment of leucaena. The experiment was on an Ona fine sand soil (sandy, siliceous, hyperthemic Typic Alaquod) that had been fertilised in previous years. The soil had pH 6.3 and contained (mg/kg Mehlich-1 extractable) 22 P, 24 K, 973 Ca, 235 Mg and 582 Al (Mylavarapu and Kennelley 2002). Following rotovation, ~20-cm high beds × 30-cm top-width spaced 2 m apart were made on half of the area. Single-row plots were marked out in both the bedded and non-bedded (flat) areas. On July 30, 2002, inoculated seeds (not pre-germinated but scarified by soaking in sulphuric acid for 35 min) and 3-month-old seedlings of the selections were manually sown and planted, respectively, 50 cm apart in single-row plots. Three seeds were sown and thinned to a single seedling at each 50 cm spacing 2 weeks after planting. On October 15, 2002, an adjacent area was similarly prepared, sown and planted as above. Plant survival in both the July- and October-established portions was measured in both November 2002 (fall) and February 2003 (winter).

There were 4 treatment factors: sowing or planting time: July and October; bedding: raised and flat beds; selections: K636, K784, K749, K340 and LxL (Table 1); and propagule: seed and seedlings; in 4 randomised complete blocks. Data were analysed as a multi-split plot experiment with sowing time as the whole plot, bedding as the sub-plot, selection as the sub-sub-plot, and propagule as the sub-sub-sub-plot. Mean separation was as in the previous experiments.

Results

Experiment 1. Seedling emergence and survival of leucaena on a poorly drained soil

The effect of selection × soil water status interaction on seedling emergence was significant (Figure 1). Seedling emergence of all leucaena selections (78–93%) and calliandra (53%) in freely drained soil was significantly higher than their respective values (2.5–20% and 13%) in waterlogged soil. Seedling emergence of leucaena selections and calliandra in waterlogged soil was similar, except that significantly more seedlings of K749 emerged than of K636, K340,

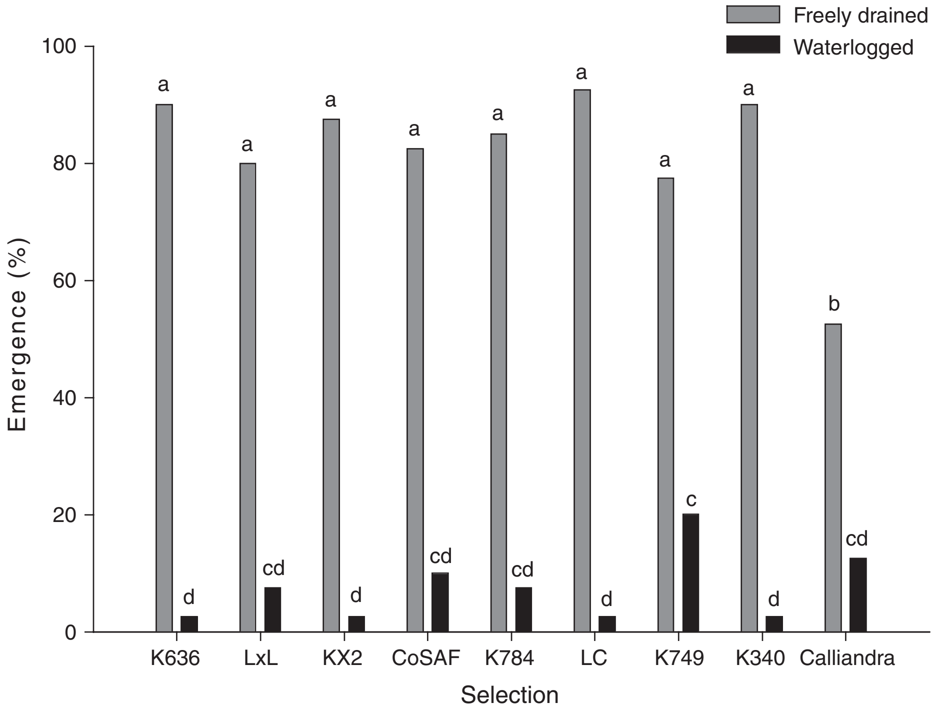

Figure 1. Percentage of seedlings that emerged after 15 days averaged over 2 runs. Means with different letters are different (P < 0.05).

LC and KX2. For all selections, all of the 15-day-old seedlings in freely drained soils survived when subsequently subjected to waterlogging for 15 days.

Experiment 2. Effect of soil water status on leucaena survival

There were no signs of adverse effects of soil water status on plant shoots. Leucaena seedlings in treatments where water was maintained at or above the soil surface began developing aerenchyma tissue at the stem bases at 10–14 days after treatments began. Where water level was maintained at the soil surface, aerenchyma developed from the crown up to 3 cm above the soil surface. Where water level was maintained at 3 cm above the soil surface, aerenchyma was formed from the crown up to 3 cm above water level (6 cm in total).

Shoot heights after 4 and 8 weeks of application of soil-water-status treatments, and shoot and root dry weights at harvest varied significantly among selections and soil water status, but there was no interaction of selection and soil water status (Table 2). Similar trends in shoot heights among the selections were recorded at 4 and 8 weeks. Among the leucaena selections, K784 had the tallest shoots and LC, LxL and K340 had the shortest. All leucaena selections were significantly taller than calliandra (Table 2). Shoot, root and total dry weights varied between selections with highest values in LC, K784 and K636 and least in calliandra and K749. The percentage of root in total biomass (data not shown) was 50–56% in K636, LxL, K340, CoSAF and LC; and 42 and 48% in K784 and KX2, respectively. The least was 34% in K749 and calliandra.

The trends of shoot heights at 4 and 8 weeks among the soil-water-status treatments were similar but plants growing with water maintained below the surface were significantly taller than those of the other treatments (Table 3). The greatest shoot, root and total dry matter yields

Table 2. Shoot height at 4 and 8 weeks after initiation of treatments, and shoot, root and total dry matter yields of selections averaged over soil-water-status treatments.

Selection[1]	Shoot height		Dry weight		
	4 wk	8 wk	Shoot	Root	Total
	(cm)		(g/pot)		
K636	25.7 bc[2]	35.2 bc	4.0 ab	4.6 a	8.6 a
LxL	21.3 c	26.1 d	2.8 bc	3.5 a	6.3 abc
KX2	29.2 b	35.1 bc	3.2 abc	3.0 abc	6.2 abc
CoSAF	26.4 bc	33.6 bcd	3.2 abc	3.3 ab	6.5 ab
K784	38.5 a	46.2 a	4.2 ab	3.1 abc	7.3 a
LC	21.3 c	26.7 cd	4.6 a	4.6 a	9.2 a
K749	31.4 b	35.8 b	2.3 c	1.2 bc	3.5 bc
K340	21.5 c	29.3 bcd	3.3 abc	3.6 a	6.9 a
Calliandra	12.6 d	16.4 e	2.1 c	1.1 c	3.2 c

[1] See Table 1.
[2] Within columns, values followed by different letters are different ($P < 0.05$).

Table 3. Effects of soil water status on shoot height at 4 and 8 weeks after initiation of treatments, and shoot, root and total dry matter yields averaged over selections.

Soil water status	Shoot height		Dry weight		
	4 wk	8 wk	Shoot	Root	Total
	(cm)		(g/pot)		
3 cm above soil surface	24.4 b[1]	27.3 b	2.0 c	1.6 c	3.6 c
At soil surface	25.2 ab	30.4 b	3.0 b	2.5 bc	5.5 bc
15 cm below soil surface	29.4 a	39.5 a	5.0 a	4.8 a	9.8 a
Freely drained	22.8 b	29.6 b	3.2 b	3.7 ab	6.9 b

[1] Within columns, values followed by different letters are different ($P < 0.05$).

were obtained where water was maintained below the soil surface and least where water was above the surface. The percentage of root in total biomass was greatest in the freely drained soil (54%), followed by below the soil surface (49%), and were similar for water at (45%) or above (44%) the soil surface (data not shown).

Experiment 3. Effect of sowing time, bedding and propagule on field establishment of leucaena

Total rainfall (1187 mm) received between July 2002 and February 2003 was greater than the 60-year average (902 mm) for these months (Figure 2). Mean minimum/maximum temperatures were 22/32°C during July–October 2002, 13/25°C and 11/22°C in November and December 2002, and 7/20°C and 23/31°C in January and February 2003, respectively. There were 3 occasions in January 2003 when temperature dropped to ≤0°C. Freeze damage was noticed on some plants, but damage was not widespread and did not appear to be associated with treatment.

Seedling survival, measured in November 2003, indicated an interaction between sowing time and selection (Figure 3). Survival of K784, K749 and LxL was poorer with July than October planting, while K636 and K340 were not affected by sowing time. The effect of the propagule × selection interaction was also significant (Figure 4). Survival of K636 and K340 seedlings was similar for both propagules, but for the other selections, survival was greater with seedlings than with seeds. Survival was not significantly affected by bedding, averaging 81% and 68% for raised and flat beds, respectively.

In February 2003, a sowing time × selection interaction significantly affected seedling survival (Figure 5). Better survival of K784, K749 and LxL was obtained with October planting than with July planting, while survival of K636 and K340 was similar at both planting times. There were also significant sowing time × propagule, selection × propagule, bedding × sowing time and bedding × propagule interactions (data not shown). Survival of transplanted seedlings was

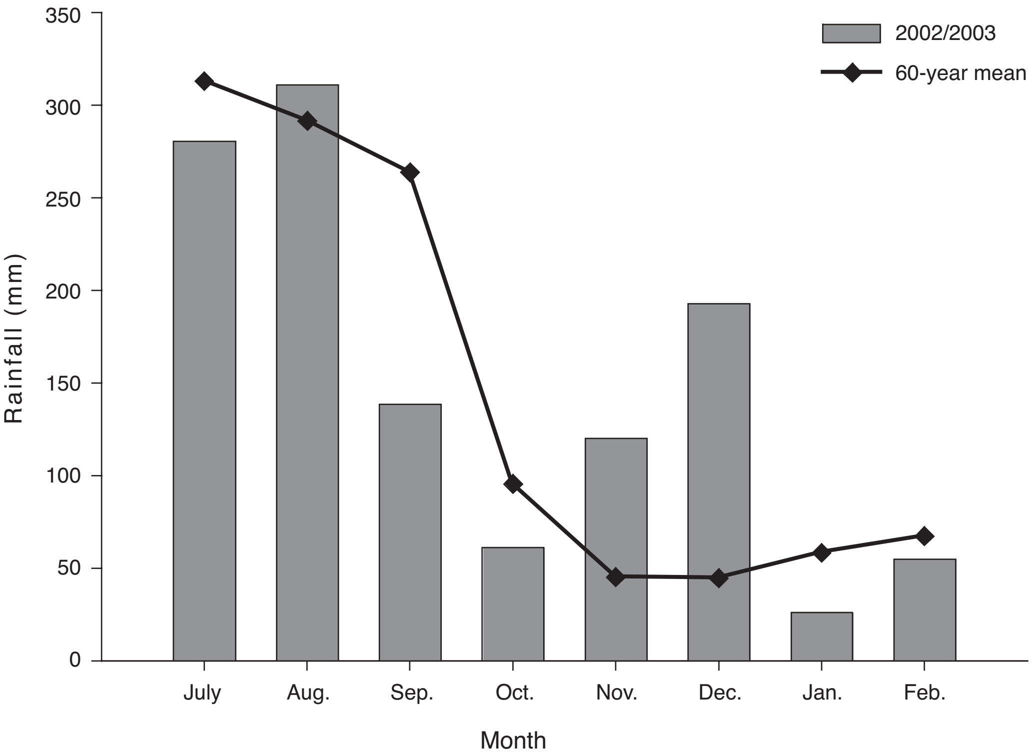

Figure 2. Observed rainfall for July 2002–February 2003 compared with the 60-year mean rainfall at Ona, Florida.

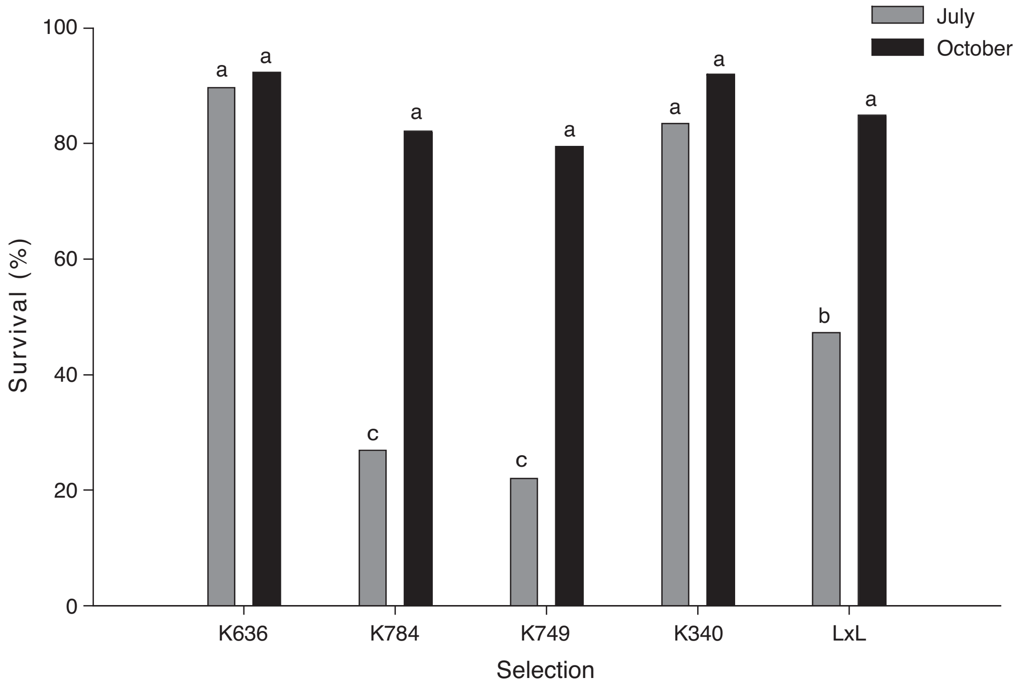

Figure 3. Means for percentage survival in November 2002 showing leucaena selection × sowing time interaction. Means with different letters are different (P < 0.05).

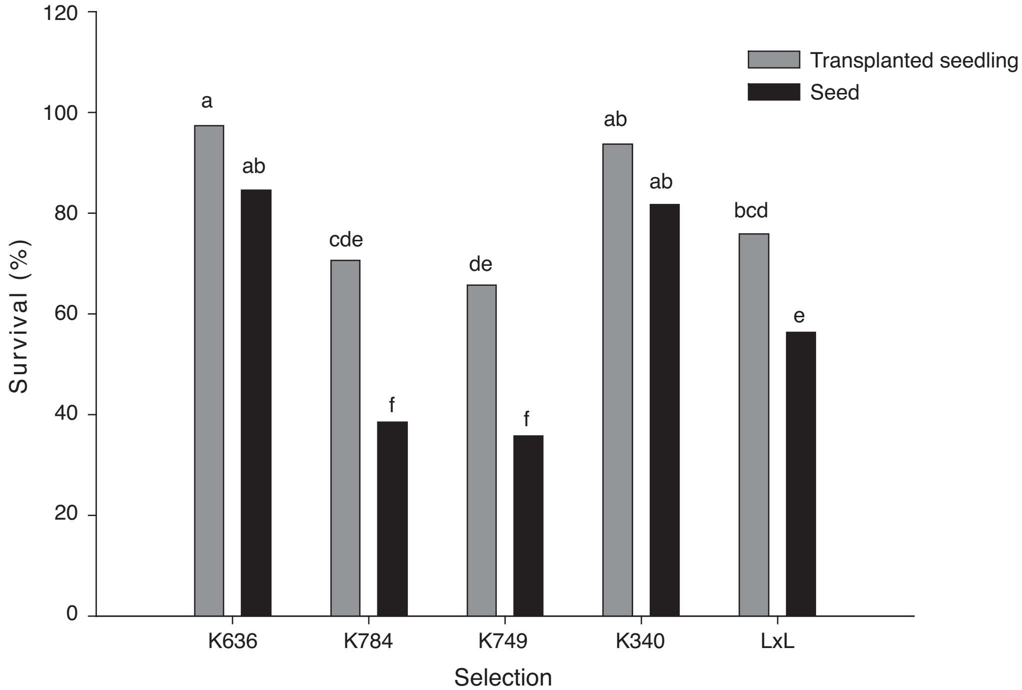

Figure 4. Means for percentage survival in November 2002 showing leucaena selection × propagule interaction. Means with different letters are different (P < 0.05).

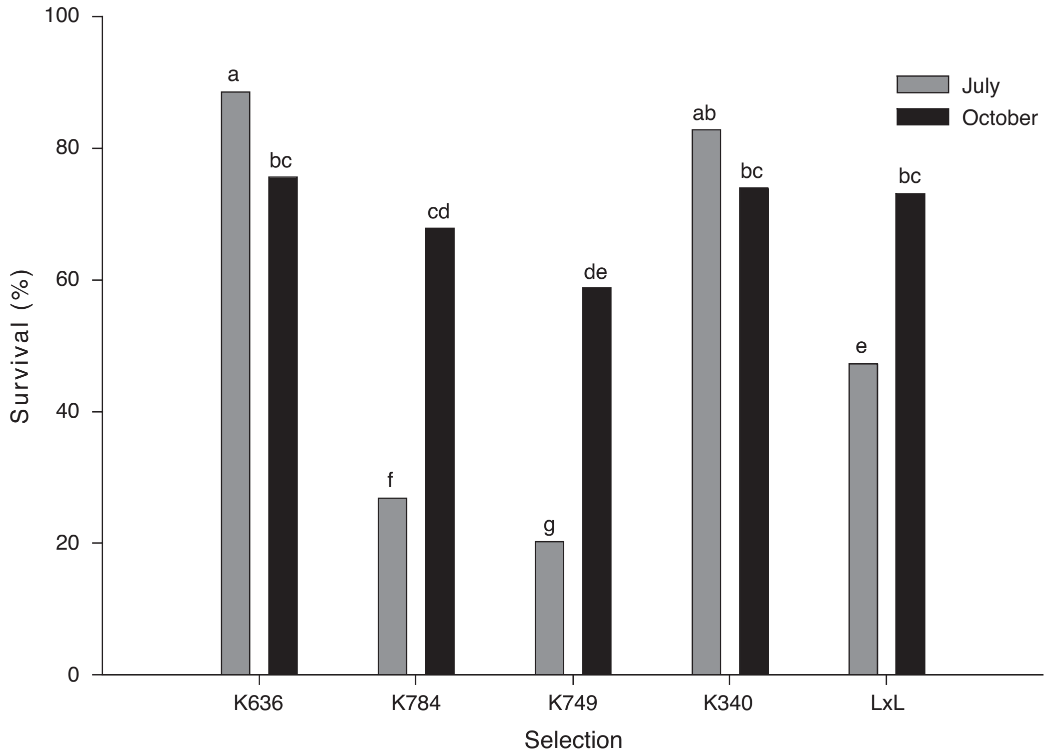

Figure 5. Means for percentage survival in February 2003 showing leucaena selection × sowing time interaction. Means with different letters are different (P < 0.05).

better when they were established in October (96%) than in July (62%), whereas survival from seed (44%) was poorer and remained at the same level at both times of sowing. Transplanted seedlings of K636 (96%) and K340 (92%) had better survival rates than those of K784 (70%), K749 (63%) and LxL (76%). Transplanted seedlings of all accessions survived better than seeded plants, while the survival of seeded K784 (38%), K749 (36%) and LxL (56%) was less than that of K636 (85%) and K340 (82%).

With July establishment, bedding did not affect survival in February (mean = 53%), but with October establishment, sowing or planting on flat (76%) was better than on raised (64%) beds. Survival of transplanted and seeded plants on raised beds was similar (mean = 80%), but when established on flat beds, seeded plants (44%) survived better than transplanted seedlings (39%).

Discussion

The results of our study indicate that the main effect of waterlogging is on seedling emergence rather than survival. Under waterlogged conditions, emergence of all leucaena selections was depressed. However, there was no seedling mortality after emergence, indicating an ability to persist under waterlogged conditions. Increased transpiration, reported in seedlings <3 months of age (Shelton 1994), and the development of aerenchyma (not previously reported) on stem bases observed in our study, might be the physiological and anatomical adaptations that enabled the seedlings to persist under waterlogging. Thus, once established, leucaena can apparently survive seasonal soil moisture excesses (Shelton and Brewbaker 1994). Without drainage and bedding, established leucaena has persisted for >15 years and endured many instances of waterlogged, even flooded (1–2 cm), soil at Ona, Florida.

The reduction in growth of leucaena, when water levels were maintained at the soil surface or above, confirms the findings of Brandon and Shelton (1997) that leucaena shoot height is reduced in low-lying areas following periods of higher than normal rainfall. The superior performance of leucaena seedlings in soil, where water level was maintained at 15 cm below the soil surface, demonstrated that leucaena would benefit when its roots have access to soil moisture during early growth. In the lowland and coastal areas of Pakistan, Qureshi *et al.* (1993) reported that, even though leucaena plus other shrubs and trees were not tolerant of waterlogging, they benefited from some irrigation.

Roots are generally more sensitive and more adversely affected by waterlogging than shoots (Shiferaw *et al.* 1992; Davies *et al.* 2000). In our study, the percentage of total biomass in roots was lower where water level was at or above the soil surface. Under the anaerobic conditions prevailing in these treatments, especially at the higher daytime temperature during the experiment, root growth and respiration would have been restricted (Kramer 1951). Leucaena roots would also have been predisposed to damage and rotting. In alfalfa (*Medicago sativa*), Zook *et al.* (1986) reported that flooding caused severe root injury attributed to a root-rot disease, especially at high temperatures. However, in a study of woody plants, including *L. leucocephala*, the cause of death in plants that showed symptoms of waterlogging was from asphyxiation, not by disease organisms (Nema and Khare 1992).

Plants that are tolerant of waterlogging are able to persist by several mechanisms including the production of adventitious roots, increased water uptake, excretion of oxygen to aerate the immediate area around the root or its diffusion from the atmosphere through gas spaces that occur between cells within plants (aerenchyma) (Ponnamperuma 1972; Singh and Ghildyal 1980; Shiferaw *et al.* 1992). In tolerant plants, root growth and formation of adventitious roots are restricted to areas above the water while older submerged roots senesce and die (Tran-Dang *et al.* 1977; Kretschmer *et al*. 1990). In our glasshouse study, the most apparent response by the leucaena selections to waterlogging was the formation of aerenchyma at the stem bases. Oxygen deficiency in waterlogged conditions induces the formation of aerenchyma tissues (Kuo and Kuo 1993; Taiz and Zeiger 1998). Aerenchyma is commonly found on stem bases of *Aeschynomene* spp. (Kuo and Kuo 1993) and *Sesbania* spp., which grow well on Spodosols in Florida (author, personal observation), and both species are well known to be tolerant of waterlogged soils (Miller and Williams 1981; Whiteman *et al.* 1984; Shiferaw *et al.* 1992; Shelton 1994). Although there was no significant selection × soil water status interaction, *Leucaena* K749, which did not have well developed aerenchyma, and calliandra, which did not produce aerenchyma at all, had shorter plants plus least biomass production and percentages of biomass in the roots (~34%). By restricting root growth, waterlogging limits nodulation and N fixation, nutrient and water uptake and other physiological processes on which shoots depend, subsequently stunting shoot growth (Kramer 1965; Minchin and Pate 1975; Jackson and Drew 1984; Kozlowski 1984).

During early growth, *L. leucocephala* allocates greater resources to total biomass underground (Ezenwa and Atta-Krah 1992). Since poor establishment of leucaena is related in part to delayed development of lateral roots, that are responsible for nutrient and water uptake (Ezenwa and Atta-Krah 1992; Cook *et al.* 1993), allocation of more biomass to the roots could have contributed to the consistently good performance of K636 and K340. The outstanding performance of these selections was not unexpected as they have performed well in terms of ease of establishment, dry matter yield and nutritive value in clipping and grazing studies in south and central Florida (Austin *et al.* 1995; Valencia *et al.* 1996).

The better survival with transplanted seedlings than with seeds is in line with other reports (Shelton 1994; Valencia *et al.* 1996). Since leucaena does not compete well with weeds, greater success is achieved if plants (seeds or seedlings) are established on fully prepared seedbeds (Shelton and Brewbaker 1994). In our study, bedding had no significant effect on survival of July-planted seedlings but did adversely affect seedling survival of the October planting. Soil conditions were drier, and bedding aggravated the drought. This indicates that propagule, selection and time of planting were more important factors for seedling survival than raised beds. Survival of transplanted seedlings was better when establishment was delayed until October rather than planting in July. It is noteworthy that seedlings stand greater risk of freezing with October planting.

Conclusion

Waterlogging severely reduces emergence and limits leucaena seedling establishment by restricting root and shoot growth. Since leucaena tolerates drought better than flooding, sowing before or after the rainy season may permit good establishment. Leucaena selections K636 and K340, which had high survival when established with seed and seedlings, and in wetter and drier parts of the summer, appear better suited to south Florida, and offer more flexibility in establishment options in terms of land preparation, time of planting and propagules. Hitherto, uniform field establishment in commercial plantings of leucaena has not been achieved. Long-term studies utilising larger areas are needed to confirm the applicability of these findings to improve commercial plantings.

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